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Studies of the Role of Forest Vegetation in Surficial Run-Off and Soil Erosion[1]

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THE object of the studies reported in part in this paper is to evaluate in accordance with scientific method factors affecting surficial run-off and erosion chiefly from forest soils. In considering the influence of man and his agencies in changing regimens of run-off and erosion, it is necessary to begin with the natural undisturbed condition of a landscape. Relicts of primeval vegetation facilitate such comparisons. Where, however, no relicts are extant, difficulties and uncertainties surround the reconstruction of normal processes. Assuredly the most reliable device in the second case is the setting aside of areas protected from all major outside influences such as grazing, trampling by stock, use or destruction of vegetation and cultivation for agriculture. In such areas the returning vegetation will in time give a more accurate expression of the potentialities of the control of run-off and erosion, under prevailing climate, than any other contrivance. The norms of processes under conditions undisturbed by human or artificial agencies or their nearest approximations are required as bases for comparative studies of this nature. These studies specifically apply to humid and semi-humid regions favorable to the support of complete mantles of vegetation.

Interdependence of Vegetation and Soil. The soil coating of a landscape under humid and semi-humid climate is dependent upon processes of weathering of the original consolidated or unconsolidated rock material, influenced by climate, through time, under the control of a mantle of vegetation as Shaw has indicated (1927). Vegetation plays a remarkable role (Glinka, 1927, page 8); it accelerates weathering by supplying in the decay of its products carbon dioxide to acidify soil waters; it supplies food for myriads of soil micro-flora and fauna (Grimmett, 1926; Feher, D., 1929); it in turn prevents the rapid removal of soil by protecting the surface against erosive forces; in favoring the accumulation of a thick coating of soil, it again tends to retard the rate of weathering of the country rock (Shaler, 1891). On the other hand, vegetation is unable to develop to its maximum state and growth without a deep coating of soil to serve the dual function of supplying a site and food for an active soil fauna, and of storing water as field capacity moisture at the disposal of plant formations. A remarkable interdependence of long standing exists between the soil and its vegetation. The development of soil and vegetation have progressed dependently through periods of time often to be measured in geological terms.

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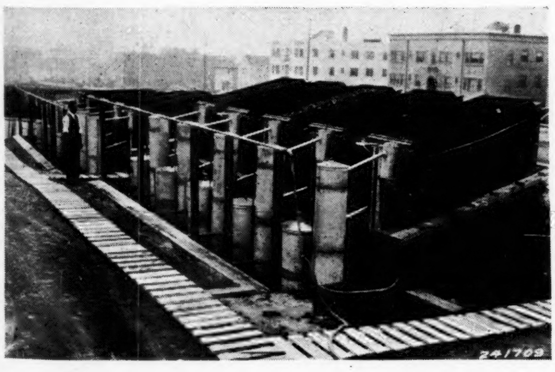


A general view of the tank installations at Berkeley fitted to apply artificial rain up to intensities of 4 inches per hour continuously. Each tank is fitted with two rain troughs to measure the rainfall catch, with a sediment trap and run-off collector tank as well as with a seepage collector tank. Each collector tank is equipped with graduated glass gages from which readings are made systematically. The five tanks in the middle distance are employed in studies on the inceptional processes of erosion

The soil coating at the same time is subjected to erosional processes whose operations are reflected in the sculpturing of landscapes. An erosional potential is produced principally by gradients of land uplift, by precipitation and by soil texture. Under natural conditions within climatic regions specified the soil coating is subjected to the operation of erosional potentials under vegetative control. Topographic form represents, therefore, the operation of erosional processes generated by erosional potentials as affected by geological structures and the restraining influences of a natural mantle of vegetation responsive to climate. Erosion under these natural conditions may be designated a geologic norm of erosion. McGee (1891, p. 445) refers to this concept as "old erosion."

Topographic form is profoundly influenced by vegetative control of the soil surface. Cross-sectional profiles of slopes under vegetative control generally take on a form convex to the sky. Exceptions to this rounded form occur on the valley walls of rapidly intrenching streams where the sectional profiles are straight, forming V-shaped canyons. Such trenching occurs where erosional potentials are high in gradient and in flow of water. But drainage channels containing flows of lesser transporting capacity or intermittent lie in convex walled trenches when under vegetative control. Exceptions to these general resultants occur under conditions of moist climates where "flowing earths" or creep soils are highly developed as indicated by Ramann (1928, p. 85).

Land degradation under vegetative control of the surface proceeds in somewhat the following manner: An incising stream creates gradients on the faces of lower slopes, by undercutting, in excess of the angle of repose of soil. Soil creep, to which Shaler (1891) early called attention, is thus generated at the lower face of the slope. A slow glacier-like movement is imparted to the soil, the rapidity of which depends upon gradient, nature of the parent material, soil texture, degree of saturation of the soil, and roughness of the buried country rock surface. Under humid climate, vegetation and its layer of ground litter effectively controls or restrains surface removal, except

where gradients exceed the angle of repose of the soil material. Burrowing rodents and animals, however, by their innumerable workings are effective agents of soil movement toward drainage channels to which Grinnell (1923) has correctly called attention. Except on steep gradients, however, vegetative control at the surface is sufficient, under complete cover, to maintain rounded topographic forms convex to the sky.

In the absence of vegetative surface control topographic profiles are concave to the sky. Typical examples are apparent on every hand in mountains of arid climates supporting a sparse vegetation. Destruction of a mantle of vegetation so as to expose hitherto protected coatings of soil to the full extent of erosional forces commences a change in topographic profile curvature. The first indications appear in the profiles of gully channels, which are concave to the sky. Likewise, the number of drainage channels are multiplied in great numbers, as Shaler (1891) observed, by baring a soil of its vegetative control of the surface. Erosional phases typical of arid regions may be induced in humid regions when the protective mantle of vegetation is destroyed by whatever means.

A Geologic Norm of Erosion. The concept of a geologic norm of erosion has been indicated in the author's studies thus far (1926, 1929, 1930) and is of primary importance in all studies of the influences of mantles of vegetation on the regimen of water drainage and erosion. A geologic norm is not, however, a uniform phenomenon. It responds to varying supplies and intensities of precipitation, to faulting of rock structures and to landslides. It represents the inevitable processes of degradation and planation of land forms above sea level, measured in geologic time units. The geologic norm of erosion may be considered both as a limit of any measure of erosion control and as a basis for the measurement of the acceleration of erosion.

Accelerated Erosion. Erosion accelerated above the geologic norm is a second important concept. It represents the augmented operation of an erosional potential caused by the removal of the control exercised by a mantle of vegetation. The destruction or consumption of vegetation may be caused by fire, by destructive lumbering, by overgrazing, by smelter fumes, or by clearing and cultivation for agricultural crops. The important condition which gives rise to accelerated erosion has been found in a series of our studies (1929) to be the baring of the soil surface which favors the sealing effect of muddy suspensions of surface flow occasioned by the higher rain intensities. Accelerated erosion is induced in a dual manner by the removal of a protective mantle of vegetation and by the exposure to erosion of a thick layer of finely comminuted soil which had been the product of vegetative control. A number of factors influence the rates of accelerated erosion. Such rates have been found in experimental studies to vary from a few to several thousand fold the geologic norm of erosion measured on areas under an undisturbed mantle of vegetation (op. cit. 1930).

The significance of the disturbance of the delicate interdependence of vegetation and soil upon the maintenance of the productivity of land for human societies has been variously interpreted and met. Reference is made to the early stimulating work of George Marsh (1874) whose inferences possess shrewd accuracy. Responses to trends of processes of accelerated erosion have varied with the genius of peoples and economic forces to which they have been subjected. It is only within the past decade that the significance of suicidal agriculture from erosion, emphasized by Bennett and Chapline (1928) has received anything like a nationwide consideration in the United States, despite such early convincing works as those of Shaler (1891), McGee (1891, 1911) and Glenn (1911).

The objective in the studies, which has been the author's chief interest for a number of years, arose in large measure from the conspicuous lack of provision on the part of engineers for protection against accelerated erosion within catchment areas draining into important engineering structures and conservancy works. Recommendations have been made in former studies (1927) that a certain percentage of the benefits of conservancy or irrigation projects should be set aside from the first for erosion control within tributary watersheds. It was first necessary, however, to discover the significance and trend of processes of accelerated erosion. Such a purpose required that various factors in a complex phenomenon be isolated and evaluated experimentally. The reduction of rates of erosion to or approximating geologic norms is, likewise, the surest safeguard of engineering works.

A partial view of the lower end of the surficial run-off plots at the North Fork installation. The six plots in pairs are fitted to measure the rate and volume of surficial run-off from natural soil surfaces under natural vegetation and from burned surfaces. The plots have projectional dimensions of 10 by 108.9 feet, being each 1/40 acre in area. The shelter house contains the recording instrument with which two rain gages and six run-off measuring instruments are electrically connected

Accordingly, studies of the influence of forests on streamflow from their inception by Belgrande (1853) were critically examined. It was concluded from a perusal of reported studies that the effort to measure one condition within a watershed, such as the presence or absence of a forest cover by a resultant, namely, streamflow, of a number of factors would invariably bring about confusion in this subject. To avoid the perpetuation of this type of confusion, experimentation was begun to isolate various factors at work, to measure their influences separately, and later to synthesize and trace the influences of these factors into larger and larger units of watersheds.

It soon became apparent that wide variations were to be expected in experimentations of this nature. This fact likewise disclosed the possibility that conditions of favorable soil and water conservation may deteriorate within the limits of experimental variation and thus proceed to ruinous conditions without detection in stream gaging such as has been employed.

The run-off plot was thereupon adopted in place of the watershed as a unit of experimentation as has been described elsewhere by the author (1926, 1929). The immediate purpose was to discover the influence of a mantle of vegetation, in contrast to a completely bared soil by fire or by cultivation, on the inception of processes of superficial run-off and soil erosion. Studies as reported (1926) demonstrated that a mantle of vegetation maintained a condition of greater absorption of rain than a bare soil surface throughout rains up to 12 inches fall in 40 hours. It was suspected that the layer of forest litter was the most important part of the mantle of vegetation in maintaining this condition. Whereupon another series of experiments were designed and installed at Berkeley to measure the influence of litter apart from its producing over canopy as compared with a bare condition of the soil surfaces caused by fire. In these experiments artificial rain was applied to a depth of approximately 200 inches. The layer of litter was discovered to exert an influence far beyond its own water-holding capacity in reducing immediate surficial run-off and erosion. The

ratios of surficial run-off varied from burned surfaces threefold that from litter covered surfaces, off Holland Sierra sandy loams, to thirtyfold from Altamont clay loams (Table I), whereas the ratios of eroded material varied from 50 to 6000 fold. Run-off waters from litter-covered surfaces remained clear under the heaviest applications of artificial rain, whereas that from the burned surfaces was muddy. The reason for the remarkable differences in run-off were found by another series of experiments to be that muddy suspensions of run-off water filtered out at the soil surface to form thin layers of fine-grained material. This thin layer at the surface thereupon determined the rate of percolation through the entire soil profile, independent of the latter's capacity for percolation. Thus it is indicated that the macro-structural features of a soil profile responsive to burrowings and activities of soil fauna and the decay of roots in a natural soil are not permitted to favor a normal rate of percolation where the soil surface has been bared and exposed to the direct impact of rain. The conclusion from these studies was (op. cit. 1930, p. 489): The formation of a fine-textured layer at the surface of a bare soil as a result of filtering suspended soil particles from percolating muddy water is, therefore, concluded to be the decisive condition which increases surficial run-off from bare soil surfaces.

Gradient of Slope and Intensity of Rain. Among other factors affecting surficial run-off and erosion thus far studied are gradient of slopes and intensity of rain.

The influence of gradient of soil surfaces is now under study at Berkeley. A series of 60 experimental runs have been completed with the Aiken soil series. A sample of 17 tons of this soil series was collected near Placerville and transported to Berkeley and returned to original volumes into experimental tanks. Other soils are to be subjected to a similar series of experimentation.

The installation consists of five large tanks each having a projectional surface area of 20 square feet, and a soil depth of 3 feet. Provision is made for changing the gradient of tanks from 5 to 20 per cent, and for the application of artificial rain up to intensities of 4 inches per hour continuously.

While the results thus far of this experimentation must be considered preliminary, yet a few important indications or trends were disclosed in the runs on the Aiken soil sample as reported by the author and Sundling (1930). They are as follows:

1. Where the soil surfaces are bare and otherwise uniform, except for gradient from 6 to 23 per cent, little or no difference in run-off factors occurred under rain intensities exceeding the maximum rate of percolation for the bare soil surfaces

2. A distinct correlation between gradient and amount of eroded material was disclosed until the formation of erosion pavements, which in turn tended to equalize the amount of erosion for gradients from 6 to 23 per cent

3. The development of an erosion pavement is an indicator of erosion and later is an important factor in primary and secondary stony soils in retarding erosion until drainage streamlets acquire sufficient volume and velocity to transport pebbles. Thereupon gullies are formed which favor undercutting and erosion proceeds apace

Table I. Surficial Run-Off as Percentages of Run-Off Plus Seepage During Experimental Runs of 1927 and Repeat Runs of 1928 (op. cit. 1930)

Soil Series	Aiken		Holland		Altamont			
Tanks	I*	II*	III	IV	V**	VI	VII	VIII
Experimental runs (70) March to August 1927	30.7	3.5	31.2	13.0	48.6	3.6	47.1	4.7
Repeat runs (10) August 1928	38.7	0.7	40.8	21.9	66.7	1.3	58.5	1.4

*Conditions of soil and tanks were rendered as uniform as possible, except that forest litter on odd-numbered tanks was burned clean for comparisons in surficial run-off from surfaces with forest litter intact.

**Tanks V, VII and VI, VIII are duplicates representing theoretically uniform experimental conditions. Differences between duplicates represent average experimental variations.

Erosion Pavement. Erosion pavement is a term which was given by Shaw (1929) to the accumulation of pebbles and rock fragments on an eroding soil. When a soil, hitherto protected from direct erosive forces by a mantle of vegetation is bared and exposed, the fines are soon washed away leaving behind the pebbles. These accumulate to form a distinct pavement similar in all respects to desert pavement. Erosion pavement is an unmistakable evidence of sheet erosion and when well developed tends to protect the surface from further rapid removal of soil. Thus erosion factors were found to diminish, although run-off factors remained remarkably constant for all gradients throughout the experiment.

The installations employed in these experiments were designed to measure factors operative at the inception of erosional processes. Thus the effect of the rapid accumulation of run-off streamlets of sufficient volume and velocity to cut gullies through erosion pavement was not measured. Different installations will be required for this purpose. Conditions which determine the absorption of rain as it falls are of paramount importance in water and erosion control and in maintaining erosional norms. Experimental results affecting erosion pavement have, therefore, special interest.

The formation of an erosion pavement is conditioned on the presence of pebbles and rock fragments in a soil, such as is characteristic of primary and immature secondary soils with included rock. Absence of large fragments in aeolian or loessal soils precludes the development of an erosion pavement, with the consequence that gullies form promptly and are incised in response to erosional potentials of gradient, precipitation and soil texture.

The Factor of Rain Intensity. It was early recognized in these studies that intensity of rainfall obviously would play an important part in determining the rate of surficial run-off as well as erosion of soil. Instrumentation was designed to measure the rate of run-off from plots as well as the intensity of rain. To facilitate the employment of plots in regions difficult of access, a run-off measuring tipping bucket was designed and used. The principle is identical to that of the tipping bucket rain gage, the only difference being that the run-off tipping bucket is designed sufficiently large to measure typical run-off from plots up to 1/40 acre in area. Both the rain gage and run-off tipping buckets are caused to record on the same continuously moving strip chart. The first instrument was put into use during the rainy season of 1926 at Tsingtoo, China. Since the incorporation of these studies into the work of the California Forest Experiment Station, several improvements on the original instrument have been made.

A complete installation such as is now in operation at the North Fork center of work on the Sierra National Forest consists of six plots, each having 10 by 109 feet projectional surface area. The plots are laid out in pairs to measure variations to be encountered in sampling of a single condition. One pair of plots is located in undisturbed natural forest-brush cover characteristic of the woodland brush type of the Sierra foothills. One pair was located on an area on which all cover was cut and burned down clean in the fall of 1929. The third pair was located on an area on which the cover was cut and burned in the fall of 1930. One pair of the burned plots will be permitted to restock itself naturally so that the course of run-off and erosion may be followed during the period of return to equilibrium. The second pair of burned plots will be kept in a bare and denuded condition throughout the life of the experiment.

Run-off for each plot is collected in baffle troughs at the lower ends of the plots, thence conducted through sediment traps and thence through the automatic recording run-off tipping bucket instruments. Two automatic rain gages are in operation on the area.

All measuring instruments are connected electrically with a Bristol strip chart recorder located in a shelter

house. All instruments record synchronously on the same sheet of strip chart moving at the rate of ½ inch each five minutes. It is thus possible to plot, as has been done for each storm, the intensity of rainfall and the corresponding rate of surficial run-off from each surface.

Eroded material is measured out of the baffle troughs and the sediment trap which is designed to pass only the clay fraction of sediments into the discharge. Until this present season it has not been convenient to keep the eroded material separated by storms. Thus comparisons of eroded soil are made only by rainy seasons.

These plots are located on a west facing slope with a gradient averaging 31 per cent for the plots. The cover of vegetation had suffered the fate of frequent fires of the Sierra foothills but had not been burned over for 8 years. Detailed mapping of the vegetation disclosed a predominance of Ceanothus cuneatus (Hook) Nutt. and Aesculus californica (Spach) Nutt. in the cover. A few oaks, Quercus kelloggii Newb., Digger pine Pinus sabiniana Dough., and western yellow pine Pinus ponderosa Dough., occurred widely spaced over the site. A thin layer of forest litter from ½ to 1 inch had accumulated since the last fire.

The soil is an unmapped series derived from granodiorite, and resembles closely the Holland series. Mechanical analysis shows it to be a fine sandy loam. The profile shows distinct but an immature zonation into horizons. The soil is leached free of $CaCO_3$. Burrowing of insects, larvae and spiders run through the profile in countless numbers to a depth of 30 inches. Large channels through the soil have been left by the decay of roots of brush species and trees. So permeated was the profile with these burrows that it resembled Swiss cheese. The importance of this macro-structural feature of the soil, which is quite independent of the soil texture, has not yet been subjected to measurement. It is doubtless of highest importance in favoring percolation of rain waters under high rain intensities. The results to be reported below may in part at least be attributed to conditions which favor or prevent the functioning of myriad perforations to considerable depth in percolation of rain waters.

Data from the installation at North Fork are given to serve as an example of the recorded influence of a cover of vegetation upon surficial run-off and erosion. Table II sets forth the summary record of the rainy season of 1929-30. Surficial run-off from the covered plots only occurred from snow storms. The most of this resulted from the melting of snow that had drifted into the baffle troughs. The effect of burning the slashed cover, thus simulating a heavy forest fire, was shown in three distinct ways. They were:

1. High comparative surficial run-off from burned plots
2. Formation of numerous drainage channels on the burned surface in contradistinction to a total absence of them on the covered plot
3. Large amounts of eroded mineral soil from burned surfaces in comparison with a small accumulation of leaves and litter in baffle troughs from the covered plots

Of special interest, however, are the detailed plottings of each storm, summarized and plotted for burned Plots 403 and 404. The following items are plotted from the strip chart:

1. Intensity of rainfall to a minimum time interval of one minute
2. Cumulative rainfall
3. Intensity of run-off expressed as second-feet per acre to a minimum time interval of one minute
4. Cumulative run-off expressed as cubic feet per acre.

Discussion of Results. Two significant results appear in the data of rainfall and run-off from the plots covered with a natural mantle of vegetation, and from plots burned bare of this vegetation. They are (1) that under intensities of rain up to as much as 2.4 inches per hour no surficial run-off was measured from the covered plots, except where snow drifted into baffle troughs, and (2) that the soil surface burned bare yielded rates of run-off up to over 0.3 second-feet per acre, representing 200 second-feet per square mile. The maximum total of run-off came from a plot during the first rainy season following burning when a total of over 400 cubic feet per acre ran off under a total rain of 2.82 inches for the storm. Eroded material from the burned plots reached maximum totals of 3 cubic yards per acre for the rainy season of 1929-30. This material was predominantly mineral soil, whereas material from the covered plots was essentially the organic material of litter. Similarly with surficial run-off there is no basis for calculation of ratios between the contrasted plot surfaces. Baring the forest soil of its vegetative cover has produced surficial run-off above a norm for the season of complete absorption of precipitation waters, and has thereby generated accelerated erosion far in excess of the norm in comparative vegetated areas.

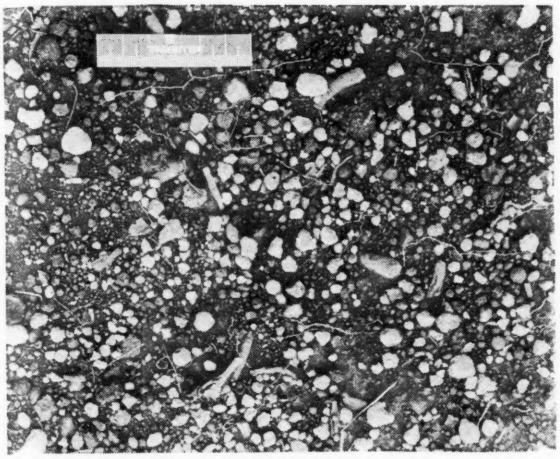
The correlation of the effect of intensity of rain with rate and total surficial run-off from the burned plots present certain interesting difficulties. When totals of rain and surficial run-off by storms are plotted against each other, no correlation is shown which emphasizes the role of rain intensity. On the other hand, when intensities and rates of run-off are plotted against each other, definite general trends are apparent. Nevertheless wide variations within these results occur, which require examination.

Two factors appear to be operative in determining the rate of surficial run-off. One is the configuration of the plot surface as it affects the collection of surficial flow into streamlets over the surface. Where surficial flow rapidly collects into drainage channels, the increased volume reduces the hydraulic radius and frictional resistance to flow. Thus the rate as well as quantity of flow may

TABLE II. Summary of Rainfall, Run-Off and Eroded Material for Run-Off Plots at Northfork, Sierra National Forest Season of 1929-1930

Date	Form of precipitation	Cu. ft. of water falling on each plot	COVER PLOTS					BURNED PLOTS				
			401		402			403		404		
			Cu. ft. of water caught as run-off	% run-off of rain falling on plot	Cu. ft. of water caught as run-off	% run-off of rain falling on plot	Average % of run-off of two plots	Cu. ft. of water caught as run-off	% run-off of rain falling on plot	Cu. ft. of water caught as run-off	% run-off of rain falling on plot	Average % of run-off of two plots
Dec. 1 to Dec. 31, 1930	Snow	97.66	0.0	-	0.0	-	-	0.0	-	0.0	-	
Jan. 1 to Feb. 23, 1930	Snow	924.48	0.4	0.043	0.1	0.010	0.027	6.4*	0.692	6.4	0.692	0.692
Feb. 23 to Mar. 16, 1930	Snow and rain	459.47	0.0	-	0.2	0.043	0.026	4.7	1.023	9.1	1.980	1.501
Apri. 13 to May 3, 1930	Rain	266.56	0.0	-	0.0	-	-	5.8	2.176	13.6	5.102	5.514
Totals		1748.17	0.4		0.3			16.9		29.1		
% run-off based on seasonal rain				0.023		0.017	0.020		0.79		1.66	1.22
% run-off based on rains which caused erosion				0.13		0.08	0.11		1.59		2.49	2.49
Cu. ft. eroded silt per plot			0.007	(organic material only)	0.007		0.007	1.20		2.14		1.67
Cu. yd. per acre			0.01		0.01		0.01	1.73		3.09		2.41
Ratio			1		1		1	173		309		241

*Tally on tipping bucket of 403 not working in one storm, so same value taken for 403 as for 404 in this storm.



The development of an erosion pavement from the Aiken soil series (Placerville, Calif.), showing the accumulation of rock fragments as the fines are washed away by surficial run-off. The soil surface shows the compacted and crusted condition due to the filling of interstices with fines filtered from a muddy suspension as it partially percolates into the soil. A thin layer of fine-textured material is produced at the surface which determines the rate of percolation for the entire soil profile

vary widely from two bare surfaces uniform in other respects, except for slight configurations to be found on soils in place. It is a very difficult thing to take account of such differences in plots 115 feet long except in a descriptive way. Artificial smoothing of the surface as can be done in cultivated lands can not be considered in these experiments. The other factor is the wide and irregular variations in rainfall intensities as it affects surficial run-off. It is first evident that the fall of rain is anything but steady. The measurement of variations is limited by one-minute intervals of time and 0.02 inch by amount of fall. These units appear to be small enough for the purposes of the experiment; any further division introduces refinements which are not at this time considered justified. The amount of surficial run-off from the plot surface delivered to the baffle troughs is affected by rain intensity in the following way. Surficial run-off passes over a pervious medium, the soil, which is continuously removing water from the surface flow. At the same time, run-off producing rain intensities exceed the percolating or absorbing capacity of the soil. If such an intensity should continue uniformly for an hour or longer, close agreement could be expected in the percentage of run-off as has been found to hold for the tank studies submitted to artificial rain. When, however, a run-off intensity lasts for one minute, the distance to which superficial flow may travel determines the amount of run-off in an important manner. If sufficient time elapses between another run-off rain intensity for all surface flow to sink into the soil, quite another set of probabilities is injected into the data. The operation of various combinations in actual intensities, their durations and intervals affect adversely direct correlations. When variations to surface configuration are likewise included, we are faced with two alternatives. One would be to refine controls in area, surface and intensities to a point where direct correlation would be found. It may be worth while in time to do this, but it will involve much additional experimentation. The other alternative would be the acceptance of trends as reflecting the operation of the surface conditions through a complex of factors. The objectives in this type of experimentation must determine the refinements to be employed.

It is clear from these results that intensity of rainfall plays a decisive role in the production of surficial run-off. Our data shows that it is not until rain intensities exceed 0.5 inch per hour that heavy run-off is to be expected. When intensities approach 1.0 inch per hour, run-off becomes important, and when they exceed 1.0 inch per hour, run-off becomes heavy, equaling a rate in one instance over 500 second-feet per square mile.

It becomes apparent that no adequate basis of comparison between the run-off from a covered watershed and one burned over can be made without a careful measure of the intensities of rainfall in respective watersheds or in succeeding years in the same watershed. Intensity plays such a large role in determining the effectiveness of rain, as well as its destructiveness under given conditions, that unless its value is known no satisfactory conclusion can be drawn as to the influence of surface conditions of watersheds.

The Place of Cultivation on Surficial Run-Off and Erosion. In the studies of the effect of baring of soils formerly mantled with vegetation, by cultivation, by fire or otherwise, it was discovered that at the inception of processes of run-off and erosion the bare soil surfaces yielded many fold more surficial run-off and erosion than the soils with their natural cover of vegetation.

Thus cultivation is one of the most important agencies in inducing accelerated erosion. And unless special precautions are taken on sloping lands, the utility of the soils for agricultural crops is destroyed. In short, cultivation under such circumstances becomes nothing short of suicidal agriculture. Abandonment of lands ruined by erosion has been progressing steadily. As fields are abandoned, the forester is called in to control erosion by planting up if, happily, there may be grown timber of some use and value thereon. Such a situation now exists over hundreds of thousands of acres in the United States (Lentz et al, 1930). For this reason the forester is interested and seriously concerned with all lands whose use or abuse will at some later time cause them to be referred to him for reclamation and redemption. The forester has little professional concern with lands which are suitable and are managed for permanent cultivation. It is, however, not the case with marginal lands, or with certain methods of cultivation that will destroy their usefulness for further cultivation, and automatically thrust them as a charge upon the forester for reclamation. Such land areas become, therefore, a concern both of the forester and agricultural engineer, and furnish a zone of effective cooperation in one of the most fundamental and far-reaching works of conservation for maintenance of land productivity.

SUMMARY

Former studies of the influence of forest vegetation on streamflow have failed to disclose the ruinous processes of accelerated erosion that accompany the baring of soil surfaces of natural mantles of vegetation. When submitted to controlled experimentation it has been discovered that natural vegetation with its layer of ground litter is the most effective agent in maintaining the maximum absorption rate of soils and similarly in maintaining the geologic norm of erosion. Thus the baring of soil surfaces for any purpose, whether by accidental fire or for purposeful cultivation, is fraught with hazards. It is unmistakably indicated that the highest interests of the community in the long run should discover and specify under what conditions land may be cultivated. The same conclusion applies to any other use which may induce accelerated erosion.

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Vegetative Cover, the Water Cycle and Erosion[1]

By E. I. Kotok[2]

GEORGE MARSH, in his work "Man and Nature" (1863) and later in "The Earth as Modified by Human Action," (1874), clearly stated the situation as to the manner and extent to which human action has changed the physical condition of the earth's surface. Drawing on a bibliography of 322 works, and from his own observations, he concluded that

> "The felling of the woods has been attended with momentous consequences to the drainage of the soil, to the external configuration of its surface and probably as to local climate, and the importance of human life as a transforming power is perhaps more clearly demonstrable in the influence man has thus exerted upon superficial geography than in any other result of his material effort."

An extensive literature exists covering a period of a century and a half, which deals almost entirely with the influence of forests on climate and precipitation. Zon, in his "Forest and Water in the Light of Scientific Investigation," devotes over one-half of the space to the climatic relationship.

The classical controversies between engineers and foresters, dating back to the seventies, revolved around the part that forests play in preventing floods and regulating stream-flow. It is needless in this paper to cover in detail the discussions and investigations which resulted from this controversy. But we can point out that the conclusions arrived at by these investigators were largely based on large watershed studies, with questionable scientific control, and with precipitation and run-off data of varying accuracy.

Thus Chittenden, Willis, L. Moore, and many others were concerned primarily in proving that deforestation had no part in accentuating floods.

The problems of the relationship of vegetative cover to the water cycle and erosion involve so many complex variables that these early investigations merely cast doubts, but failed to single out the factors requiring study. Erosion, the simplest factor which can shed light on this vexing problem, was almost entirely overlooked.

In the exhaustive literature of forestry and engineering on this subject but little space is devoted to a discussion of the problems that deal directly with the process of erosion. This factor, if introduced at all, is generally referred to as a contributing cause in some basic relationship that the investigator or author is trying to establish as to the effect of deforestation on floods, changes in the regimen of streams, etc. Thus, erosion as a destructive and modifying force is frequently obscured. Marsh, however, singled out this factor more definitely than investigators before him and even those of a much later date.

True enough, erosion as a geologic process has been recognized along with the development of geology itself; but no clear-cut distinctions have been drawn by geologists or others between the normal erosive processes and their accelerated forms, as a significant measure of changes in the soil profile, which are themselves the crux of the whole problem.

Accelerated erosion, in the light of recent investigations, is the clearest evidence of the deterioration process in the natural soil profile. The soil profile, in turn, can be maintained in optimum conditions only by the continuous presence of a vegetative cover. This is the forester's field, the maintenance of a suitable vegetative cover on the earth's surface.

The Wagon-Wheel Gap experiment was hopefully looked upon by American foresters as an answer to all the complex relationships between forests and water. It was a valuable contribution, but it failed to give conclusive results on how deforestation would effect erosive processes and the consequent influence on run-off and seepage. This experiment did not denude the forest, did not make any radical change on the vegetative cover that was enduring enough to affect significantly the soil profile. It merely converted, with great rapidity, a deciduous high forest into a coppice forest. Bates and Henry call attention, in this work, to the fact that erosion was accentuated to a very limited extent only in the roads and trails where complete denudation had actually taken place. This study was executed skillfully and yielded important data on the meteorology and hydrology of a land area in the Rocky Mountains. The rate of erosion was insignificant on the treated and untreated watershed, amounting for both collectively only to 1/6 of a cubic foot per acre. The difference in rates of erosion, however, for the areas was about 8½ times, but with these small amounts, approaching normal erosion, no inferences can be drawn between the areas.

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[1]Paper presented at a joint meeting of the Land Reclamation Division and the Pacific Coast Section of the American Society of Agricultural Engineers, at San Francisco, Calif., January 1931.

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On the other hand, Sampson (1918) and later Forsling (1931), working at Great Basin Range Experiment Station in Utah, on areas of herbaceous vegetation where the density had been sharply altered by grazing, recorded striking differences in erosion and run-off.

Two comparable watersheds of approximately the same size, elevation, and soil, were grazed at different intensities, from 1915 to 1929, inclusive. Watershed "A" had its plant cover maintained at 16 per cent of the possible fully stocked ground cover for five years and then increased to 40 per cent, being carried at that density through the remainder of the experiment. Watershed "B" was maintained at a 40 per cent plant cover throughout the entire period. Watershed "B" shows for the entire period 64 per cent less in surface run-off and 54 per cent less sediment than does watershed "A" from summer rains. With an increase in cover on watershed "A" the amount of sediment carried in each 1000 cubic feet of winter run-off was reduced 53 per cent. Moreover, the erosion from summer run-off was much greater than that from winter run-off.

Lowdermilk's work (Page 107), both in his soil tanks and on the naturally vegetated and denuded field plots, regardless of the character of the vegetation, has shown that the removal of the litter and humus will immediately accentuate the erosive processes and the run-off relationship when intensities of rain reach rates of one inch per hour, even for short intervals of time. This effect appears to hold for gradients from 5 to 23 per cent, but is considerably modified by the texture of the soil exposed.

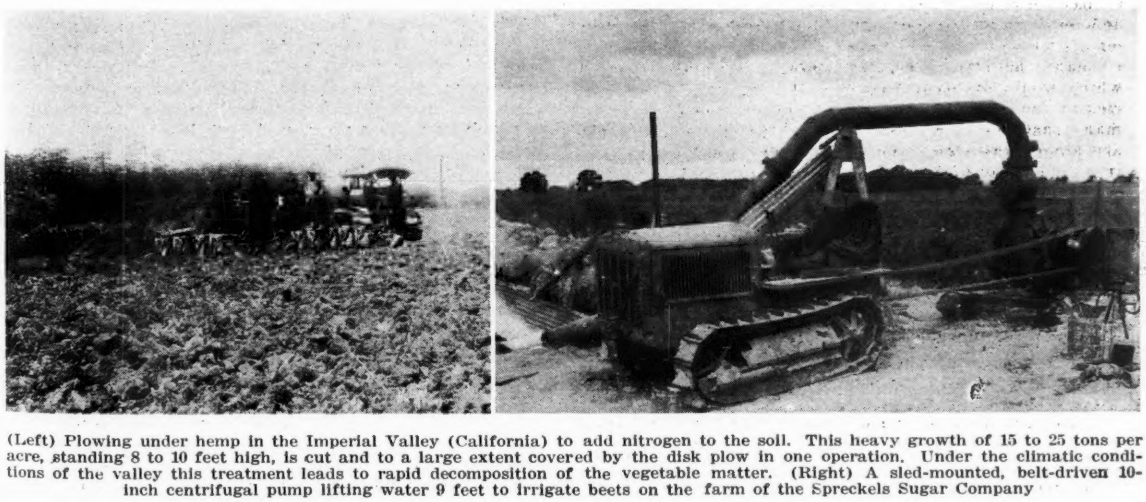
More recently Bennett and Chapline have called attention to erosion as a national menace. Bennett devotes his discussion almost solely to loss of agricultural soils by erosion through improper methods of cultivation. Farming, in the process of tilling, must deal with exposed soils which will always be subject to erosion. Much of such farm land falls in the category of marginal crop lands, and might best be allowed to revert to forest or range, until the necessity for its use as agricultural land becomes more urgent. As public recognition that such lands be converted back into forests is translated into a national policy there will be a dual job, one of arresting erosion on the spectacular bad lands scattered throughout the nation, and one of putting forests back on the lands themselves. But besides these lands, vast areas of forests, through fire and destructive logging, and an empire of range land in the public domain, subjected to the abuses of unregulated grazing, have had a continuing history of accelerated erosion. Here nature has not been given any opportunity to adjust itself. Obviously, the first step towards a solution of the problem is to place these lands under control and management, and to check the abuses at their source, be they fire, destructive logging or overgrazing. Then must follow a laborious process of reestablishing the best possible mantle of natural vegetation, building up the soil profile, and converting lands into productive forest and range.

In the attempt to connect deforestation and other vegetative destruction with changes in climate, frequency of drought cycles, torrential floods, pestilence, and plague we have failed to observe how human abuses have altered the land surface itself and removed the soil—our most treasured natural resource.

In parts of western United States where irrigation is essential for agriculture, and where water must be impounded for domestic and industrial use, the effect of changes in the vegetative mantle on the processes of erosion should receive attention. For example, California with its contemplated expenditure of one-half billion dollars for the creation of a state-wide water system, must have some concern with the manner of treatment of the watersheds.

The watersheds behind this monumental project embrace at least 20,000,000 acres of forest lands, and a like amount of brush and grassy foothills, much of which is used for the grazing of livestock. The engineering plans, so far, have given little consideration of how the land management of these watersheds will affect their investment in reservoir capacity through silting, nor in the amount of available run-off. Here for the first time on any large scale, stress is laid on a by-product of the forest which may be favorably or unfavorably influenced by the manner in which the vegetative crops of the forest are handled.

The forester here has some specific jobs to perform. We must know definitely just how fire will, through removal of the cover, litter, and humus, affect run-off and erosion, how long this process will continue, and the means we can take to hasten recloaking of the surface with a cover of vegetation. We must know which system of grazing management can be employed without detriment to the watershed values, and how lands already severely punished by overgrazing can be restored to a desirable condition. We must know, further, how various cutting methods in the forests will adversely affect this water relationship. And in this analysis we must subject the present recognized systems of silviculture and range management to the test of whether or not they accelerate erosion. Generally silvicultural and range management methods which will produce our maximum crops will perforce embody maximum safeguards against accelerated erosion.



(Left) Plowing under hemp in the Imperial Valley (California) to add nitrogen to the soil. This heavy growth of 15 to 25 tons per acre, standing 8 to 10 feet high, is cut and to a large extent covered by the disk plow in one operation. Under the climatic conditions of the valley this treatment leads to rapid decomposition of the vegetable matter. (Right) A sled-mounted, belt-driven 10-inch centrifugal pump lifting water 9 feet to irrigate beets on the farm of the Spreckels Sugar Company

Relation of Erosion to Soil Productivity[1]

By Arthur W. Sampson[2]

SOIL erosion is a natural process. It is a matter of the rate of the wearing away of the soil surface with which engineers, foresters, and others are largely concerned. They are primarily interested in the extent to which removal of natural hindrances of erosion may cause acceleration of the normal rate, and how the erosion evil may best be corrected.

Accelerated erosion and plant destruction usually go hand in hand. In any problem of regeneration of the plant cover on eroded areas, the physiology and nutritional requirements of the plant community must not be overlooked.

Soil Organic Matter. No factor is more influential in "balancing" the soil nutrients for plant growth than organic matter. Since the organic content of the soil comprises a great mass of substances of plant, animal, and microbiological organisms, it varies according to the original materials, the extent of their decomposition, and the nature of the organisms concerned in the decomposition. Eventually, a dark colloidal mass of very slightly oxidizable organic matter, called humus, is formed in the soil. Humus tends to retard soil leaching, it promotes soil aeration, increases the water-holding capacity of the soil near the surface, makes moisture available to vegetation for a longer period, increases and maintains the supply of nitrogen, and tends to "balance" the nutrient ions for the use of vegetation by absorbing them on its surface. The power of humus to absorb bases and hold them against the leaching action of water is one of its important functions in the soil. It is largely because of the activities of nitrifying and nitrogen-fixing bacteria that soils well supplied with humus are so productive. No watershed can function efficiently, nor can the fertility of the soil be maintained, with a declining supply of soil organic materials.

Leaching of Plant Foods. Probably no factor is more serious, aside from heavy erosion of the soil itself, than the leaching from the soil of its nutrient constituents. In the washing out of these materials, which so often follows the destruction of the natural vegetation, the inorganic constitution of the soil solution is readily altered through the process of exchange of bases. One element of the compound may be more readily soluble in the leaching medium than the others. In this unbalancing of the ions, the fertility of the soil is lowered. Soils with a low percentage of one inorganic nutrient ion are likely to have low percentages of others. This is because the deficient ion may either limit the absorption of the other ions, or because of curtailment in the growth and spread of plants naturally rich in minerals, a goodly portion of which would eventually be returned to the soil. Deficiencies in the inorganic elements of herbage are common in many pastures of the world. The histories of these lands are almost invariably the same. They have been subjected to protracted periods of overgrazing and depletion of the plant cover, followed by heavy sheet and gully erosion.

A deficient or an excessive amount of certain essential elements contained in the soil solution or in the solid soil phase, as Orr (1929) and others have shown, reacts very differently on plants. Because of their more general importance, only nitrogen, potassium, phosphorus, and calcium will here be briefly considered.

Nitrogen. The protein and nitrogenous bodies in plant and animal remains, which become incorporated in the soil, make up the chief natural sources of nitrogen of growing plants.

Nitrogen is lost from the soil in many ways, chief of which is leaching of nitrogen compounds, especially nitrate nitrogen, from unprotected or exposed soils, by heavy rainfall and run-off. It is also lost through decomposition of vegetation, as in the burning of lands, and by overgrazing, resulting in destruction of all but the crowns and roots of the palatable plant species. It is largely through the microorganisms that soils containing much humus are so productive. A gain of 25 to 40 pounds of nitrogen per acre per year has been recorded where the upper soil horizon is well supplied with organic matter. Amounts far in excess of this are often lost because of erosion.

Potassium. Potassium is a constituent of many silicates, such as feldspars and micas. It commonly occurs in soils and in vegetable and animal substances as chloride and carbonate, or as an organic salt. The ashes of wood, of ligneous stems, such as chaparral, and of graminaceous vegetation, contain abundant potassium carbonate, an important plant food.

Experiments by Hoagland (1930) in California during the past decade have shown that continuous cropping and farming sometimes reduces appreciably the supply of available potassium. The deficiency in some soils is of the same magnitude as that of the total potassium actually removed from the crops. Some of these complications are accounted for by incorrect irrigation, but excessive leaching of unprotected soil is probably the biggest factor. Low concentration of potassium is most common in soils receiving heavy rainfall.

Phosphorus. Phosphorus occurs both in organic and inorganic form, usually as calcium phosphate, deposited in the soil colloids, and exists both in the liquid and solid phases. The phosphorus concentration in the soil solution is very dilute, yet the soil solution is saturated with respect to phosphorus. It is held that at various pH values different cations, such as Mg, Fe, and Ca, come into solution and react with PO_4 to maintain low concentration. Where bases are lacking at a given pH range to precipitate PO_4, that is, when the soil solution is acid, phosphates are leached out of the soil. Corrective measures should involve a change in the soil reaction and an increase in the soil cations other than hydrogen. The phosphorus cycle undoubtedly involves activities in the decay of organic matter.

Phosphorus is an essential constituent of certain proteins and of phosphatides which are indispensable to all living plant cells. Phosphates cause vigorous root growth, a function of great importance where the water table is low, such as follows protracted periods of drought, and in regions of low rainfall, thereby serving to make available to the vegetation an adequate water supply. Phosphates also hasten the maturity of the plant, bringing about early flowering and fruiting, thus permitting the vegetation to "evade" late summer drought by the shortening of the growing season. Moreover, vegetation grown on phosphorus-deficient soils has been known to transpire 30 per cent or more of water per unit of plant weight than that grown on the same soil with normal phosphorus supply.

In many parts of Europe, South Africa, Australia, and over extensive areas of the United States, including California, soils are deficient in phosphorus. This condition is due to continuous cropping, such as pasturing, with very limited return to the soil of the annual growth of vegetation for decompostion; and to erosion and soil leaching, especially in humid climates. The most serious-

[1]Paper presented at a joint meeting of the Land Reclamation Division and the Pacific Coast Section of the American Society of Agricultural Engineers, at San Francisco, Calif., January, 1931.

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ly phosphorous-deficient areas of natural vegetation investigated in California are those that have been heavily grazed the year round for extended periods, with no thought of deferring or rotating the grazing to build up the humus.

Calcium. Calcium in the soil solution is derived largely from calcareous rocks, especially those in which lime occurs as carbonate. In general, it comes into solution very slowly. Calcium is essential for normal leaf development of green plants. Calcium deficiency causes stunting, discoloring, and decomposition of roots, as well as brown spotting and subsequent death of leaves. Calcium appears also to be associated with the synthesis of proteins, and with the formation of the material composing the cell wall. Leguminous plants are rich both in proteins and calcium.

Vegetation grown on calcium-deficient soils is more or less correspondingly low in calcium compounds. Malaguti (1911) found that the amount of calcium in the ash of clover growing in calcareous soils was 43.32 per cent, compared with 29.72 per cent in plants growing in non-calcareous soils. An excess of soluble calcium in the soil solution, on the other hand, is known to hinder the absorption of other ions, notably phosphorus and potassium. Livestock maintained on vegetation low in calcium exhibit much the same symptoms as those caused by deficiency of phosphorus in the feed. Sometimes the skeleton of the animal is not of sufficient strength to bear the weight of the body. In humid regions—notably where the soil is acid—calcium is more likely to be deficient than in arid regions. In all localities, ample calcium is important to maintain the soil in good tilth. It plays an important role in controlling the alkali problem.

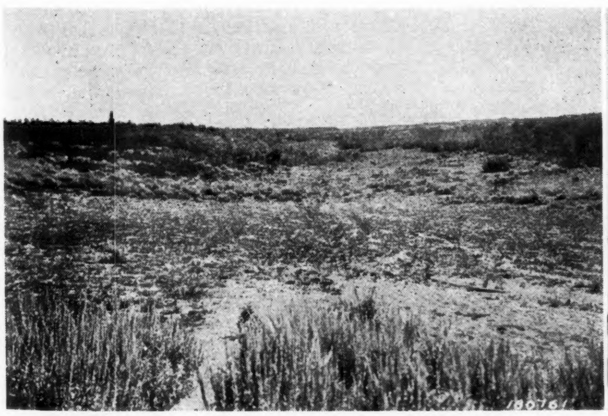
Run-off and Leaching on Selected Plots. Duley and Miller (1923), of the Missouri Agricultural Experiment Station, recorded the amount of run-off and the loss of soil nutrients on different cover crops. The land sloped at the rate of 3.7 feet per 100. The results over a six-year period were as follows: On bluegrass sod an average of 11.55 per cent of the precipitation ran off each year; on the plot with a rotation of corn, wheat, and clover the run-off was 14.14 per cent; on the wheat plot, 27.38 per cent; on the plot plowed annually to a depth of 8 inches, the run-off was 28.36 per cent; on the plot plowed 4 inches, 31.26 per cent of the water ran off; and on the plot of bare, uncultivated soil, 48.92 per cent ran off.

The amount of soil eroded per acre during the six-year period was as follows: From the bluegrass sod plot, 1.7 tons; the rotation plot of corn, wheat, and clover, 13.7 tons; where wheat was planted annually, 39.9 tons; the plot planted annually to corn, 106.5 tons; the uncultivated but denuded area, 207.8 tons; where the soil was plowed 8 inches deep but without vegetation, 214.2 tons; where the soil was plowed 4 inches deep but without vegetation, the eroded soil amounted to 227.3 tons. It is significant that bluegrass sod proved the most effective cover in minimizing both run-off and erosion, and that the greatest run-off occurred on bare, uncultivated soil. The heaviest erosion was from plots of plowed land.

The loss of fertility of the soil of these plots caused by erosion also shows much contrast. The greatest saving of nitrogen was on the grass sod area, this plot losing only 0.55 pounds as an average for two years. This small loss might easily be much more than replaced in a single season by the action of bacteria. The loss of nitrogen from the plot in corn was 40.36 pounds; from the two cultivated but fallow plots the loss was 95.40 and 73.87 pounds, respectively; and from the unplowed but exposed soil it was 98.88 pounds.

The relative loss of phosphorus caused by erosion of the plots was similar to that of nitrogen, and proved a serious consideration in the maintenance of soil fertility. On uncultivated but exposed soil the phosphorus loss was 47.47 pounds, equivalent to the phosphorus requirement for growing more than 100 bushels of wheat. On the grass-sod plot the loss was negligible, amounting to only 0.09 pound. These results corroborate those of Sampson and Weyl (1918), who recorded a marked increase in water requirements of the plants grown, as well as the production of much less vegetable matter on the eroded than on the non-eroded soils. Also in these tests the eroded soils were much lower in calcium, potash, phosphoric acid, and nitrogen than the non-eroded soils.

More recently Sinclair and Sampson (1931) have studied the relative productivity of and the normal plant succession on the three soil horizons of certain extensive soil series of California. It was found that: (1) The climax (perennial) grasses planted in phytometers grew very slowly in horizon B—or the subsoil—and produced little or no seed; whereas on horizon C—the unweathered parent material which underlies horizon B—these perennial plants, for the most part, failed to grow. In no case did they even produce flowers. Annual species, on the other hand, fructified vigorously in horizon B and produced some seed in horizon C. (2) In horizon A—the weathered, mature soil layer, which is comparatively rich in organic matter—both perennial and annual species grew vigorously, fruited abundantly, and completed the growth cycle at an early date. (3) The highest water requirement for growth was found in horizon C, although horizon B was a close second in this respect, plants in these horizons often requiring twice as much water as in horizon A per unit weight of air dry material. (4) The soil solution of horizon A contained appreciably more nitrate nitrogen, and



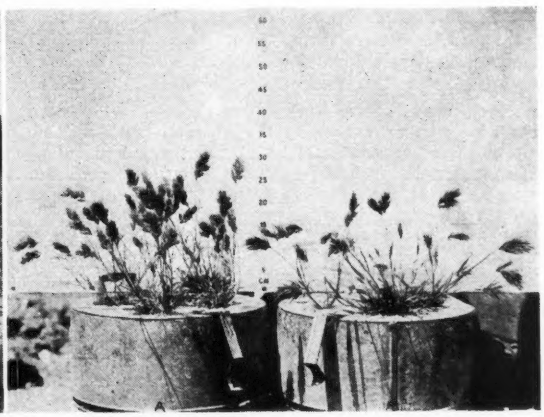


Fig. 1 (left). A depleted pasture, the result of sheet erosion and subsequent invasions by annual plants of low nutritive value.
Fig. 2 (right). Bromus rubens, an aggressive annual species grown on horizon "A" and "B" of the Aiken soil series of California. The yield on horizon "A" was much larger and of higher nutritive value

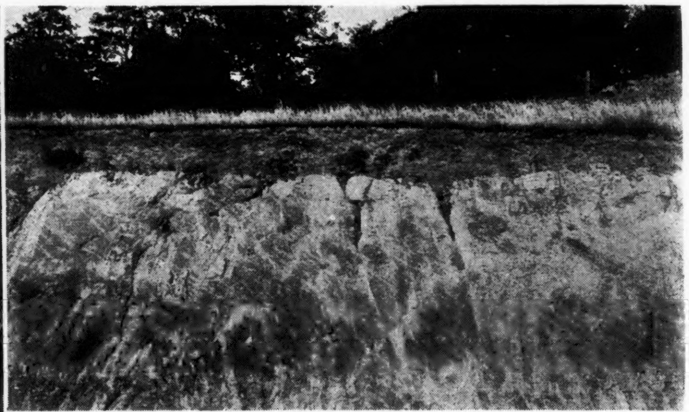


Fig. 3 (left). Destruction of vegetation at the head of a mountain stream often causes the banks of water channels to be broken down and enormous quantities of detritus deposited on fields below. Fig. 4 (above). View showing well-developed horizon "A" which produces a luxuriant growth of forage of relatively high nutritive value

considerably more phosphorus, than did the lower soil horizons.

All the points brought out relative to soil productivity emphasized particularly the importance of controlling rapid run-off, erosion and soil leaching, both in the interest of protection of water storage reservoirs and in economic crop production. The productivity of the soil, its water-holding capacity, and the run-off from grassland and forest soils are undoubtedly more or less directly proportionate to density of the vegetative cover, the amount of humus, and the development of the "A" soil horizon.

Further Studies of Forest Influences. Land management plans based on the most reliable information now available in controlling erosion should be applied as expediently as possible. These should include the working out and adoption of such improved methods of terracing, tillage, grazing, and logging as may favor maximum yield of the annual water crop. In the meantime, more intensive researches must be carried out. Studies along the following lines would appear pertinent to the adoption of better agricultural practices:

1. The specific effects of different types of vegetation —forest, brush, half-shrub, and herbaceous—on the rate of run-off, taking into account different soil types, topography, and climatic regions. Although considerable general work has been done along this line, improved methods of handling the lands with a view to prolonging the total discharge of the water should be studied and the results carefully verified.

2. The relative effect of the different types of cover on the control of erosion and on the total yield of water. Such knowledge, especially if associated with reliable precipitation records, should be of great value in calculating in advance the probable annual discharge of streams. And although carefully conducted transpiration studies appear to have a place in a comprehensive research program, such data would probably have limited practical value in water conservation through attempts to transform an established plant cover, let us say, a high forest, into one of low stature, such as grass or scrub. The natural succession will always be toward the climax cover—in the case assumed, towards the forest type. At best, the succession could only be thrown back temporarily. To attempt to conserve water by decreasing transpiration, through transformation of the cover, meaning really to foster a lower successional plant stage, would appear to be in opposition to the laws of nature and contrary to good agricultural practice. Accordingly, full knowledge of the effect of fire, through the destruction of the vegetation and organic matter, on erosion and streamflow should be carefully determined. Studies in this field already reveal the fact that the rate of revegetation varies greatly according to the species and the degree of destruction of the soil fertility.

3. Comparative fertility and methods of revegetation of the different soil horizons. The differences in fertility of the soils of the various horizons is complicating the problem of reestablishing the cover. Often horizon B is fully exposed to the elements over extensive areas; again only horizon C remains. The productivity of the different soil horizons should be studied not only as to their nutrient mineral constituents, the rate of formation of litter and humus, and the microorganisms at work, but their physical structure and their waterholding capacities must be taken into account. At the same time the growth response of different plant species must be determined in order that all horizons may be reclothed as expediently as possible.

4. A study of the precipitation cycle and the departure of the annual rainfall from the normal. Since the use of water, like that of pasture forage, must be based on normal or, indeed, on lean years, rather than on highly favorable ones, it is important that more detailed precipitation data, representative of major climatic areas, be recorded. Thus knowledge of the past may be projected into probable measures of usefulness in the future. And with better precipitation records on the more important watersheds, it would be desirable to procure more reliable measures of the streamflow and the erosion.

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Influence of Irrigation and Drainage on Farm Machinery Design and Development[1]

By Ben D. Moses[2]

DRAINAGE and irrigation projects, because of their financial set-up and their extensive operations, have done much to develop machinery for farm use.

Drainage created a demand for certain clearing and drainage machinery, and in this connection we have seen the development of the mole plow; tule breaker; large-capacity, low-lift centrifugal pump; bucket and suction dredger, drag lines, ditching machines, special subsoilers and stump pullers.

Irrigation requirements have resulted in the development of centrifugal and deep-well turbine pumps, land levellers, ridgers, dammers, subsoilers, furrowers and ditchers, while the irrigated crops have created demands for special cultivators, diggers, toppers, planters, plows and harvesters. The peculiar soil conditions and cultural practices have been factors in the development of the track-type tractors and power cultivators.

As I see the problem of more profitable production, there are several principals concerned—the irrigationist, the soil technologist, the plant scientist, the machinery manufacturer, and the farmer—and the solution of these problems lies in the cooperative effort of the entire group. The irrigationist may develop changes in methods of application that simplify machine requirements; the soil technologist may discover methods that affect the application of water; the plant scientist may discover or develop varieties that will simplify planting, irrigating, cultivating and even harvesting, and the farmer may systematize his operations so as to simplify the work of all the others. The farmer becomes the correlator of their ideas and has to take the consequences thereof.

A detailed analysis tracing the definite effects that drainage and irrigation have had upon the design and development of farm machinery would fill a volume and would be of more historical than constructive interest. I have chosen rather to point to some of the common and unusual practices, together with occasional suggestions that have come from the field. These are not arranged in any particular order but are taken up as they happened to come to mind.

Rice grows in flooded fields, and it becomes necessary to divide the land into level patches or checks by the construction of ridges following contour lines close enough together to maintain a uniform depth of water. These ridges, together with the irrigation and drainage ditches, reduce the plant area and interfere with machinery operation. One grower, recognizing the inconvenience of contour ridges, has gone so far as to level his land and construct rectangular checks.

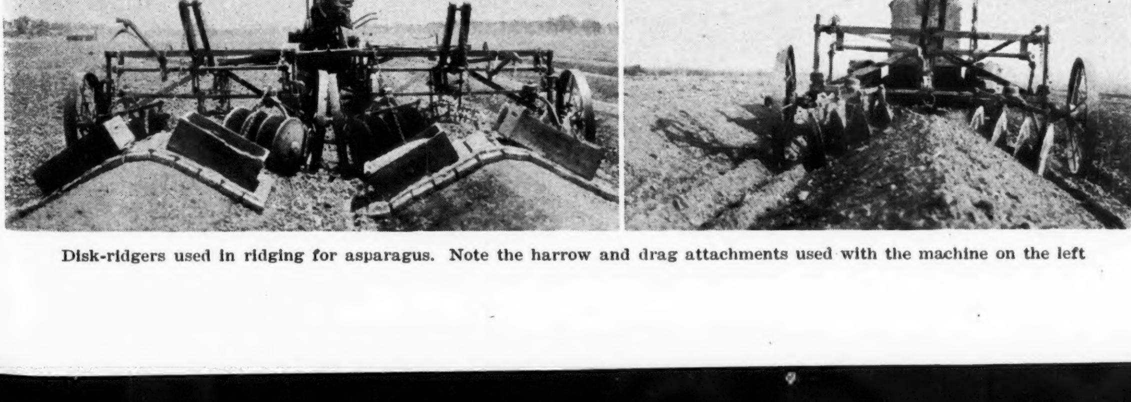
The need for levelling equipment has resulted in the construction of scrapers, drags, floats, levellers and even blade graders, to transport dirt and to even up the surface. The construction of the machines themselves has called for careful consideration of proper material for the frames and cutting edges so as to obtain maximum strength and wear with minimum weight, wheel design to reduce ground pressure, bearings to withstand the dust, and mechanical lifts and dumps, some of which operate from the scraper wheels and some from oil pumps, power take-offs, or levers on the tractor.

Because rice will not grow on top of the levees and because deep borrow pits interfere seriously with harvesting, efforts are being made to widen the levee bases and obtain the same height with shallower pits. While this type of ridge and borrow pit may not effectively increase the yield, it will certainly simplify harvesting operations. A wide, heavy ridger obtains these results but is expensive to build and heavy to handle. A grower in the Sacramento valley has constructed a steel ridger to build his levees fourteen inches above the field level and fourteen feet wide at the base.

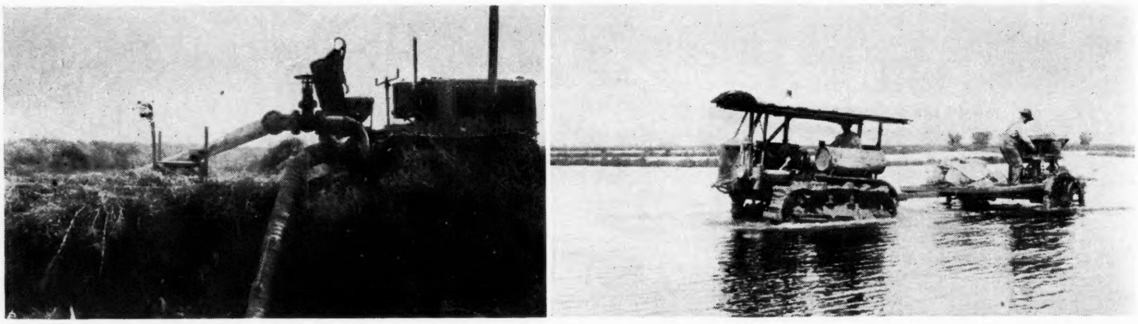
The development of equipment for levee construction in the rice and alfalfa fields has gone hand in hand with that for the orchard. Lighter implements are generally used in the orchard and the farmer frequently builds his own V-ridger, uses a blade ditcher or even throws up a ridge with a special plow or disk. The problem looks quite simple but the demands on the tools are widely different. They must handle all kinds of soil from mellow loam to tough hard clay or adobe. The ridge must be sufficiently high-measured above the field level—not the bottom of the borrow pit—must be tight, and well formed. Blade and V-ridgers move loose dirt and form a good ridge, but are not satisfactory diggers. The disk ridger digs and forms a ridge but does a poor job of packing. When ridging for rice or alfalfa, wide borrow pits with gently sloping ridges are best. When ridging for orchard basin irrigation, narrow borrow pits and high, firm ridges are more desirable. The field ridger is designed for a single purpose, while the orchard type can well be an attachment to or a modification of the plow or cultivator.

[1]Paper presented at a joint meeting of the Land Reclamation Division and the Pacific Coast Section of the American Society of Agricultural Engineers, at San Francisco, Calif., January 1931.

[2]Associate professor of agricultural engineering, University of California. Mem. A.S.A.E.



Disk-ridgers used in ridging for asparagus. Note the harrow and drag attachments used with the machine on the left



(Left) A bracket-mounted, power take-off-driven, centrifugal pump. A farmer mounted this pump on his tractor to meet his need for a mobile, low-lift pumping unit for drainage and irrigation work. (Right) Wading a flooded field to plant rice under the most advantageous conditions. This use of heavy machinery is only possible where the land flooded is of one of the heavier soil types

Ridges for contour checks are more or less continuous, but those used for basin irrigation intersect at each tree, and special dammers have been constructed to close up the gaps. Some ridgers form the intersecting ridge without forming a gap.

For best results rice should be sowed in the water as the seeds germinate better and there is no loss from birds eating the seeds before flooding. The standard seeder mounted on wide wheels or even on sled runners and drawn by a tractor, is in use in the heavy adobe fields but is not easily adapted to the mellow soils.

Over 5,000 acres of rice were planted in the Sacramento Valley last year by airplane at a contract price of \$1.00 per acre as against 50 cents an acre by the ordinary broadcaster. Less seed was used, better germination affected, and larger yield obtained. The advantages are sufficiently in favor of the airplane to warrant its use, according to those who have tried it out.

Unless rice is harvested at exactly the right time it is subject to what is called "sun checking." This reduces the milling quality, and hence the price paid the farmer. Prompt harvesting and threshing, followed by artificial drying under carefully regulated temperature and humidity conditions, improves the quality. Timely harvesting is the chief factor in producing good rice. One large grower speeds up harvesting and reduces labor by windrowing and combining. He finds that by this method he has been able to reduce his percentage of checked and cracked grain. He still encounters some trouble from sun checking of rice exposed in the windrow, and proposes a system whereby the heads will be laid on the cut stubble and at the same time covered with straw. He is now experimenting with a machine that does this work in four operations, cutting the grain with long straw, heading, placing the short heads on the cut stubble, and covering them with straw.

Water grass is a source of much trouble and considerable expense to the rice grower. Control of this weed can be effected, to a degree at least, by submergence of not less than ten inches. It has been suggested that a special drill be constructed which will dig a furrow on either side of the hill at the same time that the seed is deposited, and that if submergence is adjusted to the hill, the water grass will be smothered out, without danger to the rice.

The push binder and header were primarily developed for the dry farming areas. Their use in the rice fields has called for structural changes to take care of the ridges, borrow pits and soft ground. Wide levees, shallow borrow pits and large checks reduce header, binder and harvester troubles.

Alfalfa in California has, in general, been harvested with a mower and sulky rake. Side-delivery rakes and hay loaders have not met with general approval in the West, chiefly because of the difficulty experienced in crossing checked borders. Here, then, is an opportunity for the manufacturer to develop tools to meet these conditions, and for the irrigationist to improve ridge design and construction to permit the farmer to increase the size of his checks and to build straight ridges.

The farmer's work on his ditches does not end with their construction; he is ever confronted with the problem of keeping them open. Three years is sufficient in the Sacramento and San Joaquin Valleys to enable cattails and tule to render them useless. Burning is resorted to for the removal of weeds and grasses in some ditches, but cannot be practiced when trees are on or near the banks, and is not always effective. One farmer built an attachment to his truck consisting of a high-pressure rotary pump driven from a power take-off and a discharge pipe projecting 10 or 12 feet outward from the truck. Oil is sprayed on the tules through holes drilled about six inches apart. The oil-soaked weeds are then burned to the ground. The same rig may be used for spraying with a "weed poison." It remains for someone to develop more economical oil or poison distributing equipment that can be easily attached to a truck and driven along the ditch bank.

There seems to be a place for a light ditcher, probably of the drag-line design, of ½ to ¾-yard capacity, that can ride the bank and reach across the ditch. The present drag line used for this purpose is mounted on tracks, is self-propelling, sells for from \$12,000 to \$15,000 and operates at a cost of ten to twelve cents a yard. The designer is confronted here chiefly by a cost-reducing problem. One farmer-operator places two cents per foot per year as a maximum allowable cost for ditch clearing. This amount will vary for different conditions. However, there are certain mechanical features to be developed such as dipper lips and teeth that will dig and not clog in the tule trash and roots.

An elevating grader that distributes the dirt by means of a conveyor belt is specially adapted to digging drain ditches in subirrigated areas, and to wide ditch bottoms and banks. It travels down the furrow and piles the dirt between the plants, or along the bank and delivers the dirt clear over the bank, or into the road bed.

The centrifugal pump has been an essential piece of machinery both in putting water onto, and in draining it from farm land. The manufacturer has successfully met the varied conditions of head and quantity, and within limits, changing water tables. There seems to be something of a demand now for a pump with a capacity of about 3,000 to 4,000 gallons per minute that can be directly connected to a tractor power take-off to be used in open-ditch irrigation.

The demand for the raising of water from deep wells has resulted in the deep-well turbine, screw and ejector types of pumps. Because of the excessive cost of large wells, the manufacturer has been required to develop high-speed, small-diameter pumps. First designs used vertical pulleys driven by horizontal engines or motors. Then came the direct-connected electric motor with the vertical hollow shaft and the stator built into the head of the pump. Now consid-

erable attention is being given to a submersible motor that is set down in the well and connected directly to the pump runner shaft. The ever-changing position of the water table in different irrigation sections keeps the pump manufacturers on their toes. The development of the "cross the line start" electric motor has been augmented by the desirability of simple starting and low first cost.

Furrowers are among the most important implements used in the irrigation field. They range all the way from spring-tooth harrows, through cultivator shovels, listers, V-crowders, to blade ditchers and graders. Some manufacturers have approached a universal tool by building a frame to which can be attached any of the commonly used teeth, shovels, plows or even deep-tillage chisels. Such frames permit of adjustment to meet different row spacings. Several obstacles present themselves in such a tool, however. If the frame is heavy enough to handle the chisel points, it is unnecessarily heavy for cultivator shovels or harrow teeth. A power lift is quite desirable on the heavier cultivators but not essential on the lighter. One grower has developed his own "tool carrier," as he calls it, that raises the tools at the end of the furrow to permit short turning, thereby reducing the headland.

Whenever asparagus is hilled or cultivated the sprouts are damaged sufficiently to cause a two or three-day loss in cutting. There is need for a machine such as a spike-tooth harrow mounted in front of a disk ridger, to perform both operations simultaneously.

The track-type tractor, as an agricultural machine, was developed for the soft tule lands in the San Joaquin Valley. It was quickly recognized that it must meet the following demands of the irrigationist:

1. Be so constructed as to manipulate check borders without serious breakage to the tractor, damage to the levee, or discomfort to the operator.
2. Provide a pulley for operating an irrigation pump; this pulley became adapted to many other uses such as ensilage cutting, silo filling, hay baling and grain threshing.
3. Be flexible enough to work either in field or orchard.
4. Possess ample power to pull heavy tools required to construct ridges, dig furrows, level and cultivate, not only under favorable soil conditions, but in hard or soft ground, muddy or dry soil, sand, clay or adobe.
5. Be flexible in speed and responsive to sudden changes in load.
6. Have a short turning radius.
7. Be rugged enough to pull stumps or trees out of a roadless swamp, forest or river bottom.

The general-purpose tractor has been an effort to meet all these conditions and to accommodate row spacings and plant clearances for different crops. The irrigated crops make the severest demands.

These requirements have not only been applied to the track-type tractor but to the wheel-type tractor as well.

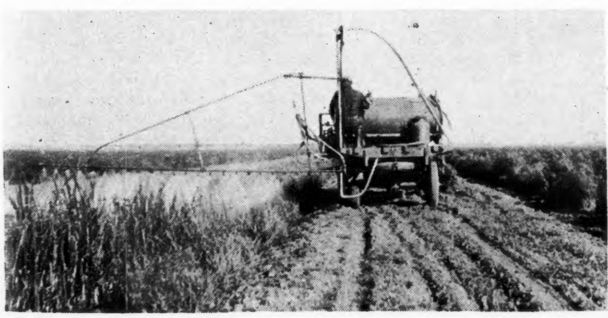
Something in the operations of irrigation farming develops a hard subsoil sometimes termed "plow sole" or "plow pan." This condition led to the use of deep tillage plows, cultivators and the special subsoiler tool. They are used to break up this hard layer so as to facilitate water penetration. After several years of observation of orchards some question has arisen as to their real value and now the pendulum is swinging back towards shallow cultivation. Disks and cultivators are being equipped with depth gages and farmers are cultivating just deep enough for weed control. The manufacturers of these tools, because of the need for great strength, have done much to improve farm machinery construction. They had to build them to stand tractor service, which carried them away from the practice of adapting a horse-drawn tool to the tractor.

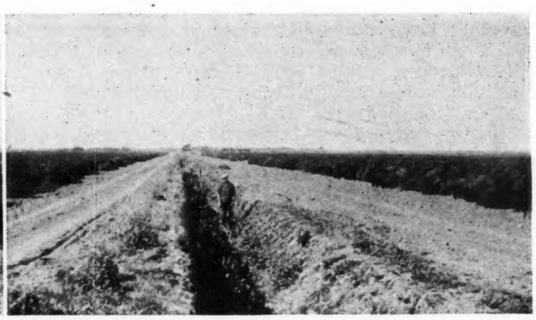
The offset disk is a development for use in irrigated orchards and permits cultivation close to the trees. Its design resulted in the application of new principles to other disk cultivators, which resulted in lighter draft and improved equipment control.

Looking backward at the application of machinery to farming operations, we see sure but gradual development, first of a tool to meet some special condition, then the modifying of farm practices to fit this tool, followed by further improvement of the tool to handle more jobs, and so on until we now have what are called general-purpose tractors, and universal cultivators. What can irrigation and reclamation offer in the way of more efficiently mechanized farming? Are we going to the large farm units? If so, then we can expect to see large dredgers on our irrigated farms digging and cleaning ditches; large tractor trains, plowing, harrowing, smoothing, furrowing and planting all in one operation. The general-purpose tractor will be used for cultivating, spraying, dusting and some harvesting. The airplane will sow some of the grain crops and dust orchards and vineyards, and some of the field crops. Irrigation water will be furnished by large operating companies in a manner similar to the method used by the electric power companies at the present time. The farmer will have none of the responsibility of getting the water into his main ditches but will have only to take care of its proper distribution. Harvesting of irrigated crops will be more and more by the combine system. Field labor will be reduced and even such crops as beets will be dug, topped and thrown into a truck by machine. The cotton harvester, too, is not far off.

On the other hand, if we go to small, privately-owned farm units we will see smaller general-utility tractors. The tractor will be convertible from a plowing unit to a cultivating, spraying or harvesting unit with little effort on the part of the farmer. His tractor will be comfortable to ride and easy to control; his pump will be automatically started and stopped; his checks will be constructed by the same tractor that cultivates. When he prunes his trees, the twigs will be cut into short lengths and plowed into the soil.

At any rate we can see the machine emancipating the farmer, and the manufacturer will not only have to keep up with the parade; he will have to keep ahead of it. He is going to have to think of better material, better design and improved methods. He will have to be both a practical and a visionary farmer—as well as an efficient factory manager—he will either rise into glory through new and better equipment or sink with his obsolete designs into oblivion.





(Left) Spraying a weed-grown ditch with oil preparatory to burning. (Right) The same ditch after the weeds were burned off

Soil Building with Terraces[1]

By A. F. Whitfield[2]

ALONG the roads through this southern country one cannot fail to notice that, in the terraced fields, gullies are formed in places on the upper side of the terrace. Too much fall has been given in these places. Also in some places gullies extend across the spaces between the terraces, these spaces being so wide that too much water is being collected before the water is checked by the terraces. In other places the terraces are well kept and successfully do their work. Both of these problems have been successfully solved by Mr. Jesse G. Whitfield, of Dothan, Alabama, and Mr. J. T. Copeland, of Mississippi A. and M. College.

No matter how well the hills are terraced, much of the richest materials of the soil are carried away by the rains. The forest too is robbed of much of its ever-increasing fertility. All of this fertility flows onward to the ocean. On its way the silt forms bars that dam the waters of the streams and cause the disastrous floods that are becoming more and more frequent as the streams are filled.

The object of this paper is to describe the natural soil, which, to the author, appears to be the ideal soil, to show the sources from whence materials that form this soil were obtained, and to show nature's method of putting them together to make a perfect soil; then to tell how a soil similar is rapidly being artificially made by regulating the amount and distribution of sand, and by impounding the muddy waters of swollen streams between terraces.

In the chalk region of Alabama is a large stream formed by three small streams that unite at near the same place. One of these streams flows over that stiff yellow clay to which the name "Ocktibbeha" has been given by the U.S.D.A. soil survey, and the black Houston clay so named by the same authority. The Ocktibbeha clay is colored by salts of iron, and the Houston clay is colored by black oxide of manganese. These clays lie above the chalk. They are both excellent soils when kept in good condition; but are waxy, drouthy and unproductive when allowed to become wet and devoid of humus. The Houston clay becomes extremely toxic to many crops, in places, when its fertility is exhausted. This is probably due to starvation of the plants, causing a loss of vitality and ability to overcome the effect of an excess of manganese. Here is an interesting field for the soil expert to work out a solution of this trouble.

This sterile condition of these upland soils is due to the lax system of cultivation that followed the war between the states.

The middle stream has cut deeply into the chalk and flows between chalk hills, capped in places by the Ochtibbeha and in other places by the Houston clay. Where small bits of undissolved chalk occur in the sediment of the valley, the soil is friable, is fertile, and is called "Trinity clay." Its color is gray from the black oxide and minute bits of white chalk.

The third small stream flows over considerable areas of chalk, blue marl and Orangeburg. The last named is a clay with much sand. It is highly colored with red oxide of iron and is a good soil. In some places it is covered with fine white sand. This sand was left clean by the red clay leaching out.

In the valley of the large stream the mixture of these clays, sand, chalk and marl form a perfect soil, rich in every element that plants feed upon, and almost entirely free of toxic salts. It is deep, friable and retentive of moisture. The valley of the big stream is one of the most fertile tracts of land in the country. The soil of this valley is called "Ochlochnee clay" by the U.S.D.A. soil survey. (There are different ways of spelling Ochlochnee and Ocktibbeha.)

It was my misfortune to be obliged to work the stiff Ocktibbeha and Houston clays. The workman had to put his weight on a spade, then shake the spade violently with his hands on the handle to get it to enter the ground to the depth of the blade.

To be able, with the help of the elements, flowing water, etc., to make a soil equal to this magnificent Ochlochnee on tracts of the poorest sands and loams and on barren pipe clays, poisoned with materials toxic to vegetation, is an accomplishment that justifies and fully pays for the years of labor and experiment that have resulted in this achievement; and the object of this paper is to make known the process to those who would make good ground of waste places, and who would restore the fertility of our rapidly depleting American soils.

If such be possible in these coal measures, one can readily see how much cheaper and how much more effective would be the results of similar projects constructed in a region where Nature has stored more of the mineral fertilizers in its hills.

In the paper read before a joint meeting of Southern and Southwest Sections of the American Society of Agricultural Engineers, at Memphis, Tennessee, February 2, 1928, and which appeared in the April 1928 issue of AGRICULTURAL ENGINEERING, I stated that the regulation of the quantity and the even distribution of sand are the hardest problems in silt control. Since then by plowing the land in ridges about three feet wide and as high as the plow will readily make them, then cutting a trench at the upper end of the ridges, opening into the spaces between the ridges as an inlet, and a trench constructed in a similar manner at the lower end of the ridges to act as an outlet, I have had sand evenly distributed over areas that needed sand. This land once a tract of white, sterile pipe clay is now as productive as the finest Ochlochnee clay.

The value of the proper amount of sand in soils cannot be overestimated. Too much is better than not enough.

A few years ago a heavy cloudburst, strong enough to wash a house with a family in it into the river, broke a terrace and deposited several inches of sand over a space in one of these projects. Some of the deepest of this sand was moved with a scraper to a tract of stiff clay that cannot be flooded. It was so arranged that no sand has been deposited where too much was left. Several deposits of silt without sand have made this space choice ground for root crops and good enough for any other crop. The improvement of the stiff clay by the application of the sand was such that several wagon loads of sand were later applied to the clay.

The streams bring down sand, clay and decaying vegetable matter upon the terraced fields, some potash, and a small amount of lime and phosphorus. The water of the springs at the foot of the hills contains sulphate of iron enough to kill vegetation in the fields. To prevent this, the water of these springs is carried away through underground tiles. The land is well drained by tiles. Plenty of lime, some phosphate and potash must necessarily be applied. These are being supplied in the form of finely ground limestone, waste lime and hardwood ashes. Small amounts of stable manure and high analysis commercial fertilizers have been used.

A greater degree of productiveness is noticeable where a larger supply of lime has been applied to this artificial Ochlochnee soil. This is due to several causes, namely breaking up the toxic compounds, correcting the acidity, changing the iron from a sulphate to an oxide, and making

[1]Paper presented at a meeting of the Southern Section of the American Society of Agricultural Engineers at Atlanta, Georgia, February, 1931.

[2]President, Clover Fork Coal Company. Mem. A.S.A.E.

gypsum of that part of the lime which takes the sulphuric acid from the sulphate of iron.

The oxide of iron formed by this reaction is a powerful absorbent of nitrogen. The fertility of the red iron soils in every district is apparent to all. (See Wheeler's "Manures and Fertilizers.") Gypsum or sulphate of lime is one of the active catalytic agencies in the soil. It has long been used to fix and preserve the unstable nitrogen of manures in barns and that of any decomposing organic matter in the soil. Gypsum retains much of the ammonia that is absorbed from the air by a highly improved humus soil.

A very rough estimate of the immense amount of organic matter in this silt enriched soil is given elsewhere in this paper, and a table showing the ratio of the absorption of ammonia by a well-improved humus or garden soil to that of other soils may be found on page 31 of Wheeler's "Manures and Fertilizers."

After several years of the above treatment, these lands have the same brown color and the same fertility as the best Ochlochnee. They retain moisture and are exceedingly friable. As far down as the depth of drainage the clays and loams, through the summer cracks, are being filled with the mud and humus from above; and the subsoil is rapidly becoming aerated. The worst part of the pipe clay, where probably as little as 0.4 foot of silt have been deposited, has been plowed to the depth of 0.7 to 0.9 foot. Holes dug to the depth of drainage show a mottled subsoil with spots of red oxide and streaks of the dark brown mud and decaying vegetation. This red and brown, when mixed, give the reddish brown (dark chocolate) color of the natural Ochlochnee clay. It is now in places below the depth of tillage and the mixing and aerated condition will continue to approach the depth of drainage.

In October 1930 a ditch was dug to make more perfect the drainage of one of the silt control projects. This cutting laid bare the roots of corn to the depth of 3.6 feet. These roots had followed the summer cracks which were partially filled with rich mud from the top and were open enough to admit air to allow the growth of the roots. Large lateral roots extended from the main roots in all directions, presenting a most unusual sight, that of corn with roots and feeders extending to the depth of more than 3½ feet. This corn in one year had changed its habits from those of a plant feeding near the surface to the habits of a plant which grows and feeds to great depths.

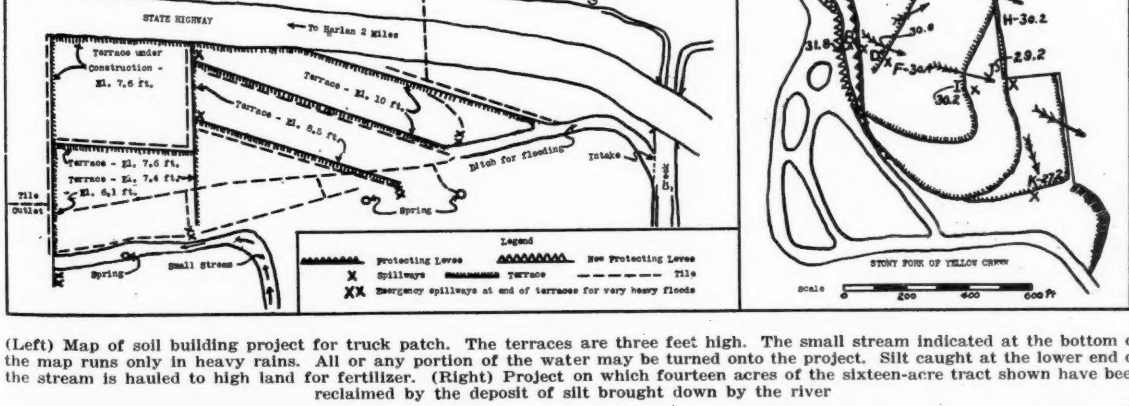
This corn was fairly good—very good not to have had rain—and would have produced three times as much had the land been thoroughly enriched and aerated to the above-mentioned depth. The soil of this part of the project will soon be thoroughly enriched by silt, and thoroughly aerated by the ditch which has been completed.

Imagine a soil varying from 3 to 5 feet deep, or as deep as one elects to put his drain tiles; this soil covered periodically with a dressing of silt containing the richest ingredients of eroded fields and forests; with mineral fertilizers artificially applied, when such ingredients are not plentiful in the rocks and soils of the hills of the districts; this soil filled with the silt and fertile from top to the depth of drainage; open to that extent which allows roots to grow to depths beyond the habitual reach of the plant; great absorption power for air and gases; holding moisture to nourish the plants, and giving out gradually a small portion of this moisture in times of drought to refresh the leaves with dew, and to add to the humidity of the air—such are the conditions to which these silt-control projects are rapidly approaching.

In the average crop made on these silt-control projects, the increased production of one year, due to the improvements, more than pays for the construction work of the ditches and terraces.

A rough estimate of the amount of the organic matter in the silt-enriched soil was made by taking a sphere of the soil from a place where about 0.7 or 0.8 foot of silt had been deposited by the floods of six years. This had been mixed by cultivation with the original soil of the field. The sphere was kept by a hot grate a week, until it ceased to lose weight by evaporation. The sphere was then kept red hot for several hours. When broken into hemispheres it showed that the organic matter had burned from one-half the volume of the sphere. The loss in weight showed the amount of thirteen tons of dry combustible (organic) matter per acre of 0.5 foot depth. Supposing the unburnt portion had lost half of its organic matter by distillation, the result is the astounding amount of 19½ tons of dry organic matter per acre,—equal to 40 or 50 tons of damp leaves gathered from the forest and distributed over an acre of land. To this must be added the large amount that has gone into the numerous summer cracks of the subsoil.

Analyses of mud containing 0.72 to 1.37 per cent nitrogen, 0.0 to 0.22 per cent potash, and 0.26 to 0.35 per cent phosphoric acid are reported on page 109 of Wheeler's "Manures and Fertilizers." This compares very favorably with the analyses of stable manures given on page 21 of this book; and the great efficiency of stable manure, due to the microorganisms, may be imparted to the fertile silt by the application of a small amount of the stable manure. The humus silt may be a good culture bed for these microorganisms, and the mixture of soil with the



(Left) Map of soil building project for truck patch. The terraces are three feet high. The small stream indicated at the bottom of the map runs only in heavy rains. All or any portion of the water may be turned onto the project. Silt caught at the lower end of the stream is hauled to high land for fertilizer. (Right) Project on which fourteen acres of the sixteen-acre tract shown have been reclaimed by the deposit of silt brought down by the river

manure prevents the loss of nitrogen caused by burning or fire-fanging of the manure. Dry soil scattered over the manure in barns is excellent for preserving the manure.

The question has been asked, and it is the only adverse criticism of the plan, "Does not the water seeping through the flooded land leach out a great quantity of the fertility?" The water flowing over disintegrating rocks and soils carries with it both dissolved fertile matter and fertile matter in suspension. When the current is checked, much of the matter held in suspension is deposited. Nearly all is deposited, when impounded, between the terraces made to control the silt; some of the material in solution goes on with the water. More is absorbed and retained from the seeping water by both the top soil and subsoil. If this were not so, the soils of the earth would become barren. There is some waste of both dissolved and suspended material through seepage, as a heavy rain after severe dry weather washes through the summer cracks enough to slightly muddy the water flowing from the tiles. The goal of all rocks and soils above sea level is to get to the sea.

Half an acre of land next to a toxic spring had no treatment except flooding and drainage. The water from the spring drying left the sulphate on top of the ground. This damaged or killed vegetation. After the water of the spring was carried away underground and the larger part of the sulphate had been leached out of the soil, the land produced fairly well, but frequent cases of diseases in the plants were caused by the toxic salts being brought to the surface by capillary attraction. These damaging salts, when changed by proper treatment, become valuable fertilizers. This half acre was left untreated for several years for purpose of experiment. Three tons of damp hardwood ashes, equal to about 2¼ tons of dry ashes, were applied to this half acre of land in March 1930. After this application of ashes, corn, which is extremely liable to the damaging effect of the sulphates, showed none of the trouble either in the growing crop or in the matured ear.

To get into his soil all of the materials that feed the various plants and the catalytics that help the atoms of these materials to arrange themselves in the proper groups most desirable for feeding the plants and to make the soil deep by changing subsoil into soil is the aim of the soil builder. It would require an able chemist with a well-equipped laboratory to tell all that is lacking or harmful in the soils being treated, and there should be hearty cooperation between the state laboratories and the soil builders, but the crops and the profits of the crops raised on these soils show plainly that a high degree of perfection is being attained; and every effort on my part to increase the productiveness and the area of these projects is being continued.

Recent experiments conducted in various sections of the country and reported by the U. S. Department of Agriculture show that much more aluminum than iron enters into the composition of plants; and that certain salts of both metals cause disease or death to plants. Where these or any other metal occur in malignant form, they must be changed into forms that are suitable for plant nourishment or such that are harmless.

There are many toxic materials that occur in soils, the extent of the harmful effects of them varying from slight damage to crops lacking the vitality to withstand the bad effects of these materials to complete ruin of the crops. This loss of vitality may be due to unseasonable weather, sterility of the soil, or both. There are, also, instances of an excess of valuable compounds being hurtful. A good example of these is the sodium carbonate of the black alkali plains of the West. I had a very profitable experience with this last mentioned salt years ago on the desert of Arizona. I venture the assertion that they can all be cured.

I am now raising excellent corn, tomatoes, peas, beans and other vegetables on land that is being enriched by silt containing much fine coal and slate from the refuse dump of a coal mine. Analysis of the coal shows 1.78 per cent nitrogen. There is enough coal in this soil to make it coke when burnt. To make a crop on such land, the evil effects of the sulphur compounds of this refuse must be eliminated.

My silt control projects are situated in a coal region where the strata contain much iron and sulphur combined in their most toxic forms; and it is with much interest that many are noticing the increasing productiveness resulting from the rich silt, that is being deposited upon the soil from the still waters held between the terraces and the changing of undesirable salts into those salts that are necessary for the health and growth of the crops.

By leaching alone the soils become less acid and toxic every year, and would in time become neutral. By liming they quickly become neutral. By heavy liming the desired alkalinity can be obtained. It requires unusual rain to fill all the spaces between the terraces and flow over all the spillways, and in time of heavy rain the greater amount of water flowing into a well-tiled silt-control project compared with the amount flowing out is very apparent, showing that a large amount of water is stored in every rain to be gradually emptied into the streams over a long period of time.

Deep humus soils retain much moisture a long time and give out this moisture slowly by evaporation. In the Southeastern part of the United States copious dews refresh the crops and increase the yields on such soils when thin and depleted soils have no dew during severe droughts. These droughts are becoming more frequent and severe as the soils are being depleted of humus and the forests are removed.

When a large amount of the farming land is well tiled, the hills and slopes terraced to prevent erosion; and as much of the land as is possible is covered with projects to arrest, control and use the fertile silt; our dews will be more copious and refreshing to the growing crops; our rains will be more regular, droughts less frequent and severe. Bars of silt now forming in our rivers to impede the flow of water will become less and the disastrous floods will become unknown.

This improvement in weather conditions would be greatly enhanced by reforestation over large areas of the country.

This country will, under those conditions, support a dense population. Our land will become as productive and as valuable as land was when the Romans rewarded their victorious general by giving him as much land as he could plow in a day with a yoke of oxen.

Engineering Opportunity in the South

BUT the engineer will fall short if he confines his interests and abilities to strict technology. It will be his privilege and duty to enter more and more into civic activity, guiding the community in affairs having an engineering angle. Particularly will he have an opportunity to direct industry to locations of social and economic advantage to all concerned. He must cultivate the characteristic of looking beyond—of humanizing his work, and of fashioning his professional activities so that they will be of maximum social as well as economic service.

There is one ever-growing resource of the South that has been merely indicated so far, yet perhaps it is as important as any. This is the university-trained technical graduate. Although tremendously handicapped by lack of funds for teaching staffs, laboratories, and other facilities, the southern universities are turning out each succeeding year more, and better-trained, engineering graduates. They will form the great part of leadership in the future progress of southern industry, which must offer them the best possible opportunity of development.—Concluding paragraphs of an article on this subject in the April, 1931 issue of "Mechanical Engineering."

Economic Problems of Western Reclamation[1]

By John W. Haw[2]

AT THE outset I wish to record my conviction that the problems, economic and otherwise, of western reclamation are no more numerous or more difficult of solution than the problems of middle-western, eastern and southern agriculture.

One of the problems of western reclamation is a matter of mental attitude of people who deal directly with reclamation, and on the part of the general public who have been given, by western people, an exaggerated idea of their seriousness. The public has had this impression in some manner substantiated by depreciation of the value of the securities issued to construct projects of fundamentally unsound character. Those compelled to daily grapple with these problems because of their limited horizon may believe that irrigated agriculture has been particularly singled out to endure more than its pro rata share of trial and tribulation, and certain it is that in the halls of Congress such opinion rather generally prevails. As to this latter situation, it could scarcely be otherwise. At each session of Congress irrigated agriculture as represented by federal projects goes through the economic clinic regularly conducted each winter at both ends of the Capitol building with attendant sensationalism and publicity. So frequently has it been good business for irrigation projects to represent themselves as faced with problems beyond their control that delegations sent down to pass through the clinic have gradually developed histrionic technique and have for several years, and are now, playing the part with convincing abandon. Congress is thus convinced that western reclamation is in a bad way. No one familiar with the facts would belittle the validity of many of the claims for extension of payments, land reclassification, write-offs and suspension of payments, but I would suggest the possibility that, in attempting to convince Congress that things are not as they should be, western farmers in particular and western people in general have partially convinced themselves that they are worse off than the facts justify. I am of the belief that at least some psychological relief would be afforded farmers on federal irrigated projects by the appropriation of funds which would enable these folks to visit the place from whence they came. I am sure they would return to their irrigated farm in the west with a changed perspective as to their opportunity and the comparative difficulty of their problems. However, such suggestion may lack good taste coming from a railroad man interested in checking a distressing decline in passenger revenues.

That there are real problems concerning western reclamation—serious ones—I am ready to freely admit, but at least the reclamationist would be over one hurdle if there were cultivated a more courageous mental attitude and more self-sufficiency—if there were less looking toward the federal treasury or bond holders for relief and closer scrutiny of the problem at hand to see what they might do for themselves. In this connection, the fortitude and courage of one of the old scouts on the Oregon Trail is recommended who, upon sighting a band of hostile Indians, called the men of the party together and said simply, "We are going to meet them and greet them and beat them."

Many of the present problems of western reclamation, from the standpoint of the man on the land, can be attributed to failure to make at the outset a survey as to feasibility, since the most numerous and complex problems are those occurring on projects of strictly promotional conception. In the early beginnings of arid land reclamation, particularly federal reclamation, the preliminary surveys were altogether too often studiously designed to reach a finding favorable to construction because of benefits to be realized by local real estate operators or because of their supposed merit from the standpoint of practical politics. Unfortunately the West is now strewn with sick, dying, dead and putrefying projects, mute testimony to the fact that mere delivery of water to arid land may create a temporary but not a permanent oasis in the desert. It is doubtful if these ill-conceived projects which have wrecked the lives and hopes of so many settlers ever made the promoters any money. Certainly in the long run they have retarded rather than accelerated community, state and regional development, and they must rise like Hamlet's ghost to disturb the slumber of the politicians that argued for their approval. It is just too bad that the picture of western reclamation must be darkened by this situation and that they have been accorded notoriety rather than the imposing array of successful ventures in irrigation of our western arid lands.

It was a happy day for the West when irrigation exploitation ceased and painstaking study of soil, colonization possibilities and economic factors went on hand in hand with the first engineering surveys. Without seeming to discourage such laudable preliminaries in the future or disparage such surveys as are now in progress or already completed, I would raise the question whether in our scrupulous care that the early mistakes should not again occur, we are not now erring in the other direction with a display of overcautiousness. I seriously question the possibility of arriving with mathematical accuracy at "economic feasibility." There are factors to be considered in any finding as to feasibility such as land prices, cost of delivering water, soil and climate which lend themselves to forecast and calculation with a fair degree of accuracy, but such equally important factors as products to be produced, markets, transportation costs, probable price trends and

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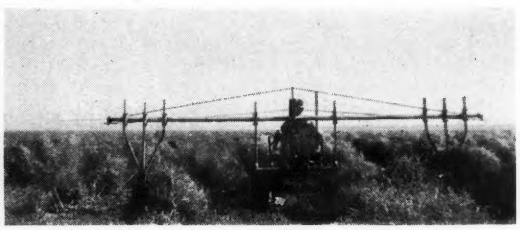


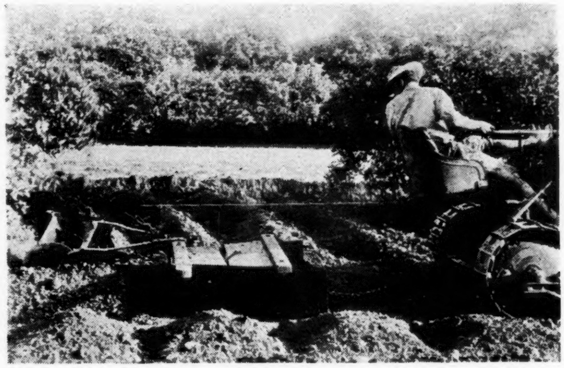
(Left) Cultivators ganged behind a special tool carrier to permit simultaneous cultivation of 16 rows of sugar beets, speeding up the operation. (Right) Special, high-level tool carrier for asparagus cultivation. This permits multiple-row operation, and by enabling the operator to raise the tools clear of the plants, makes possible a reduction in headland space

the efficiency of the farmer himself are all subject like a railway timetable to change without notice. I do not believe anyone can be "cock-sure" that a certain project cannot pay out on a certain fixed construction cost over a long term of years without allowing for a wide range of error. Probably with a fair degree of certainty we can say that a project, where fruit or truck can be produced, will lift a construction cost of $100.00 an acre, but probably not $150.00, and certainly not $200.00. Another project not so favored as to soil, climate and markets can lift $50.00 per acre, but probably not $75.00, and certainly not $100.00. Or again putting it on a basis of yearly repayments on construction, a farmer might be able to pay $3.00 to $5.00 an acre, but not $8.00 to $12.00. We have all seen conditions change so radically regarding certain economic factors that I find a general disposition to take definite findings of feasibility with a grain of salt even though there is general agreement as to their value. In my own experience and over a comparatively short period of years, I have seen a Montana project change from the growing of wheat and alfalfa to sugar beets, beans and extensive livestock feeding operations. This project was barely able to pay $3.50 per acre under the former practice; it is able to pay $6.00 per acre under practices now in vogue. I have seen farmers with a background of dry-land wheat farming lose their properties through foreclosure on a splendid federal project with a construction cost of $65.00 an acre, and frugal, industrious, experienced irrigation farmers supplant them and lift the load with ease. I have seen a portion of a project go haywire trying to raise apples and come back with soft tree fruits to meet payments with ease. Another project was changed from a scene of poverty to prosperity when, through an influx of new settlers, an unlimited liability for construction costs with attendant discouragement became in effect a limited liability. Is a project feasible or not feasible—who can be dead sure, except the "finding" is phrased in quite general terms? Therefore, while lauding the new order of things which demands that preliminary surveys other than engineering be conducted before irrigation district bond issues are floated or federal appropriations made I would commend to the attention of irrigation economists conducting such surveys, a study of economic geography, trends in price and efficiency in farm crop production and considerable latitude in their final verdict.

I am fearful that, if a survey of the economic feasibility of general farming in the eastern great plains area had been made ahead of the homesteader in the early eighties, the settlement of that area would have been abandoned or at least indefinitely postponed. It is frequently asserted that it has required three successive crops of settlers to permanently establish farming in that region. Yet today eastern North Dakota, South Dakota, Nebraska and Kansas are not classified as submarginal, and the Homestead Act is considered a piece of far-sighted statesmanship rather than a futile, blundering piece of legislation.

I believe we must carefully analyze the reasons for the early failures as well as the present successes on irrigation projects and learn to identfy insuperable handicaps from those which can and will be corrected by crop adaptation, development of profitable markets through population shifts and a changing consumptive demand, or, again, those apparent obstacles to feasibility which will disappear with the application of thrift, industry, versatility and efficiency on the part of the settler.

There does not now exist a project upon which all the settlers are a financial success nor will one ever be built. Early settlers—many of them—abandoned their homesteads on the fertile prairies of Iowa, Illinois, Wisconsin and Minnesota, and many of those now there are year by year losing their farms through foreclosure, yet it was and is unquestionably a good country. No irrigation project has ever or will ever get the ball and go for a touchdown from the kick-off. It is a battle back and forth with a touchdown eventually, as in football, for the team (or project) which displays intelligence, courage



A special ridger with a tapper attachment which can be used either to close the gaps in cross ridges or to top the ridges at intersections, for control of water flow in orchard irrigation

and has leadership, and do not think there will not be many substitutions. In fact, the team that makes the touchdown may not be the one that started the game. I repeat that I believe in an economic study of feasibility during consideration of any project, private or federal, but it should be made by a practical, forward-looking, irrigation economist and not by some conservative, eastern, mathematically inclined economist who figures entirely by rule of thumb, and who is unable or unwilling to allow for future western development and the ingenuity and resourcefulness of western people in adapting themselves to changing conditions. I have in mind that such an irrigation economist would have failed to find in favor of feasibility in a survey of the Umatilla Project in Oregon, but would have recommended the Flathead in Montana. I am sure the adding-machine, slide-rule economist would have declared against both. These two projects both got away to a bad start. One is now an admitted failure. The other is on the way toward paying out, its recovery attributable to factors which were not inherent in the original situation.

I believe it worth while to emphasize the fact that we are discussing the problems of western reclamation at a time when problems of industry, transportation and agriculture are all distorted by a critical, world-wide depression. It is the unusual individual who can maintain his poise and see problems in their right perspective during such a period. This condition of depression is not new for agriculture; it has prevailed since 1921, and it has been in this period that the problems of irrigation, the soundness of the policy of federal reclamation of arid lands, and the intrinsic value of irrigation district bonds has been the subject of argument. Industry went into the present depression in full vitality, having enjoyed a series of prosperous years during which surpluses had been accumulated and physical prosperity improved and modernized. Agriculture hit the present, world-wide, general depression with its belt already pulled up to the last notch after an experience of nine lean years. Every problem of agriculture is thus magnified and should, in my judgment, be discounted in exact proportion to the seriousness of the times. Agriculture, which certainly includes agriculture on irrigation projects, has been laboring under a handicap measured approximately by the relative purchasing power of farm products, for after all such purchasing power likewise is an approximate index to farm profits. Surely no one believes that agriculture is to be definitely or permanently held to such a disadvantage as now exists or has existed for ten years. Therefore, we should discount our western irrigation problems by the 10 or 20 per cent disparity under which agriculture generally is now laboring. The business of farming has not been prosperous, why then should irrigated agriculture be expected to enjoy any greater degree of prosperity or any greater freedom from problems? Is it not fair to believe that many present problems will either wholly

dissolve or be partially liquidated as we come out of this depression and the farmers' economic handicap is corrected as it must be sooner or later?

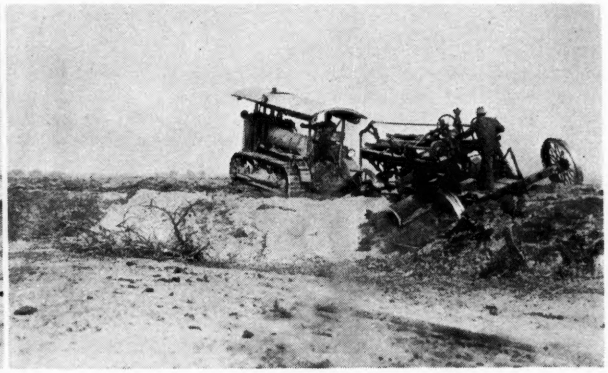
Although irrigated agriculture is the most ancient of all types of farming, there still is in this country a feeling on the part of the public east of the Continental Divide that it is an artificial practice that circumvents some fundamental law of the universe. It is perfectly proper in the best circles to drain land that is too wet or apply the lacking elements of plant food, thus enabling eastern and southern areas to become productive, but there is something not quite natural and right about raising water out of a river to be supplied to arid land to make it productive. In the current discussions of agricultural surpluses and the necessity for limiting production, the finger of condemnation is usually pointed at what is called marginal production on arid western lands. The mental process of the easterner in this connection seems to be that the Almighty preordained the rainfall regions to be a farming country—they are thus endowed with a prior right on production; if they cannot supply the market, then and then only should the westerner on his artificially watered irrigated farm be allowed a chance. Certainly it requires a twisted logic to argue on the one hand that the government cease its arid land reclamation activities, while on the other hand urging at the same time that millions be appropriated from the federal treasury for seed loans. The fact is entirely overlooked that reclamation brings in lands which produce crops of which for the most part there is no surplus while seed loans directly stimulate acreage of the great surplus crops of this country, i.e., wheat and cotton. This warped reasoning is, in my estimation, a very real problem for the reclamationist. It dissipates good will in the securities markets where irrigation bond issues must be floated; it militates against continued sanction by Congress of our present federal reclamation policy, and it prejudices the consumer against western products. The West must educate the public of this country to consider costs of supplying water under irrigation farming with the same matter-of-fact resignation that necessity for application of fertilizer, draining or terracing, is accorded in the East and South.

After all, there is gross ignorance on the part of the American public as to the role played by western agriculture in supplying the food supply of this nation. If they could be made to appreciate and properly evaluate the contribution to the healthfulness, variety and cheapness of the products placed by western reclamation on the American table, there would be an immediate rallying to the support of western reclamation and complete obliteration of the prejudices that are now all too prevalent. May I also say that, if the people whose capital and career are linked up with west coast development fully realized the extent to which future population growth and industrial expansion on the Pacific Slope is dependent

A celery crop on reclaimed delta peat land

upon a profitable agriculture on projects now built and their rapid expansion in the very near future, they would shake off their present complacency and see that the American public did understand this simple problem in economic geography. The demand for continuing development of agriculture through irrigation is a vital consideration to further growth of the Mountain and Pacific states comprising 39 per cent of the area of this country. The U. S. Bureau of Reclamation is now using all its revolving fund to complete projects planned and begun many years ago and completion of this modest program alone will require all the money flowing into the fund for the next seven years. Some way, somehow, there must be found a workable plan for expanding irrigated agriculture in the West, if we are to keep pace with the food demands of the Pacific slope and provide the balance of the United States with the fruits, vegetables, nuts, etc., which we can produce and which cannot be raised elsewhere in this country.

I presume everyone here feels that after all the great overshadowing problem facing western reclamation is as to ability to market at a profit the crops produced. Overproduction and surpluses are today by-words with the American public and the poorly informed; loose talk as to its general extent and character adds to the consternation of the irrigated farmer operating under comparatively high costs. No one, of course, should attempt to figure probabilities of profit on the basis of the situation which has existed for the last fifteen months. Buying power has been drastically affected by the depression, thus throwing supply and demand out of joint and reducing prices for farm products to their lowest level on the basis of relative purchasing power since the early part of this century. In recent normal times no one will say that in certain years and in respect to certain commodities there has not been a production beyond domestic requirements which was only relieved by a selling price below cost of production. It can be substantiated, however, that this surplus has been a regional, commodity, seasonal surplus as irresponsive and undependable as the weather conditions which constitute the chief reasons for its creation. If we are determined to speak of the relation of production to consumption in general terms, the problem should be in the main one of stimulating acreage in one crop and curtailing in another, for it is a matter of record that there is now imported yearly 800 million dollars worth of farm products. During the recent normal years, 1922 to 1928, due to hazards of climate, disease and insect pests, altogether out of our control, each year we underproduced most commodities and overproduced comparatively few. We may even say that the crops overproduced from a nation-wide standpoint are not more than a very few in a given year but because of our recent difficulties with the great staples, wheat and cotton, our troubles in this connection have been greatly magnified. One factor which also adds to our conviction that we are afflicted with general surpluses, is that perishable and bulky commodities have been frequently overproduced in one part of the country and underproduced elsewhere, yet due to their perishable character or transportation costs, it was impractical for the surplus in one section to relieve the shortage in another. If we measure production against consumption over a period of recent years, sound national policy would not dictate that our production be curbed except in the case of wheat and cotton to which reference has already been made. However desirable in theory, curtailment of production of most farm commodities, in order to bring about a profitable sale price for producers, would in practice work grave injustice on the general public with regard to many commodities each year, weather vicissitudes considered. Furthermore, such practice has in it the elements which would bring about its own defeat. The school of thought that contends that acreage can be reduced by propaganda, thus curtailing production and creating a situation where price could be artificially raised, is subject to serious question viewed in the light of certain immutable economic laws. Price, after all, not

(Left) Using a large tractor to clear land of trees, stumps and shrubs. (Right) Heavy road machinery being used to convert irregular pasture land into level fields suitable for irrigation

only records the supply and demand situation but actually controls both and in our present state of civilization price is the only mechanism so far devised which is capable of effectively influencing demand on the one hand and controlling production on the other. The western reclamationist, therefore, must gauge his probable price by what is appearing on the horizon in the way of a consumptive demand for the products which he produces.

The 1930 census just completed brings to light rather startling facts relatives to the rapid population growth of states on the Pacific slope. The facts, however startling to the consuming public in this area, are on the other hand reassuring to the farmer on reclamation projects. The seven states in this region consisting of Washington, Idaho, Oregon, California, Utah, Arizona and Nevada, had a population at the time of the 1920 census of 6,859,702. The 1930 census announces a population of 9,661,900, an increase in population of 2,802,198, or an increase of 40.8 per cent. The country as a whole had a population increase of 16,987,570, or only 16.1 per cent.

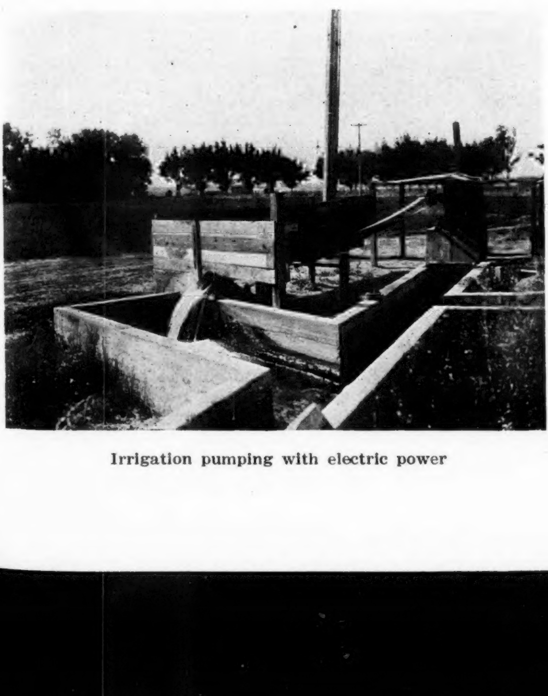
The problem of expanding agricultural production in this general area to meet the food requirements of its own people resolves itself largely into one of reclaiming arid lands by irrigation. Further growth in this region is destined to take place rapidly, only if the great staple food requirements of its people can be met from production reasonably near at hand. Any policy of curtailing irrigation expansion or stopping it altogether would throttle this growth, just as surely as depleted fertility and erosion of agricultural lands in the east is driving industry from that region west and south in search of cheap food and wholesome living conditions. Year by year the breaking point between west and eastbound shipments of the great staple food crops on western railroads is being pushed further east as this Pacific Coast demand has expanded. Pork and corn, dairy products, particularly butter, and certain types of wheat now move to Pacific Coast markets from the states in the Mississippi Valley. The Pacific Coast consumer is thus more and more forced to pay Midwest prices plus transportation costs on many staple agricultural products. This situation, if not rectified, has in it the elements which may cut down the relatively rapid population increase which has already been noted. The public is quick to recognize and shun a region of high living costs.

Irrigated agriculture in the West has a logical dual role in providing the nation's food supply. It should furnish in the main the food requirements of people residing in the area. Such staples as potatoes, wheat, meat animals, dairy products, as well as fruits, vegetables, berries, nuts and other specialty crops, should be produced for western people on western lands, irrigated or otherwise. The farmers in the Middle West and East need have no fear that such program will work injury upon them, as they do not now possess such market and they will remain securely in possession of their own tremendous natural market which is constantly expanding. The western farmer can not continue long competing with bulky, comparatively low value staple products in a situation where he can obtain at his local market, on the products to be shipped east, the eastern market price less transportation costs. But, as already stated, necessity that on these products the western consumer pay eastern prices plus transportation costs would inflict on them an economic handicap which would surely in the long run curb a natural growth in utilization of the resources of this region through industrial development. With a population growth of nearly three million in the last decade and an estimated increase of four or five million in the decade just ahead, a very large expansion of production will be necessary to provide these staple food articles for the local western market. For instance, the average American eats three bushels of potatoes and 16.9 pounds of butter per annum. If we figure merely a four million population increase in the next ten years, this area will require twelve million additional bushels of potatoes and sixty-seven million pounds of butter which should be met from production near at hand. In other words, approximately 400,000 additional cows must be maintained to provide the requirements in butter alone and at least 75,000 additional acres of potatoes. When we consider the array of other food articles consumed annually by four million people, I believe it safe to assert that one million additional irrigated acres must be brought under cultivation in the next ten years in this region if the Pacific Slope is merely to be self-sufficient agriculturally.

The second part of the dual agricultural role of this area concerns the provision of fruits, vegetables, berries, nuts and a vast array of specialized products which either it is impossible to produce at all or cannot be produced at certain seasons in territory east of the Continental Divide. The American's diet now demands a year round abundant supply of quality products of the character indicated. Western reclamation projects interspersed through the valleys west of the Continental Divide from the Mexican to the Canadian line, with an extensive range of climatic and soil conditions, are gradually being articulated into the general scheme of production of these crops. The handicap of transportation charges practically prohibits competition with the same crops of equal quality produced east of the Divide and put on the market at the same time. Western irrigation project production of these crops is gradually filling in the seasonal gaps in a year-round, adequate program of supplying these present-day indispensable food articles to the American public. It is significant that there has been of late years a large refrigerator car movement of green peas, asparagus, head lettuce and forced rhubarb from projects in the Pacific Northwest in off seasons to eastern points scattered from Montreal to Miami. Such movement would not have taken place nor would there continue to be the extensive shipment of other similar food products from the Pacific Slope

to the eastern part of this country were there no potential demand for standard, dependable grades, attractively packaged, of certain high quality products which the balance of the country could not, at least is not, providing. It is inconceivable that the consuming public of this country desires that such program be other than gradually expanded to meet the increasing demand occasioned by population growth and the unmistakable tendency of our diet toward increased consumption of such articles. With a probable population growth in the next decade of nearly twenty million people, just how is this program of an adequate supply to be maintained without extensive, further irrigation development in this area? Improved varieties, better culture and efficiency in production methods will accomplish something, but there must be a considerable acreage expansion which will come when our appropriating bodies in Congress and the investing public become convinced of the valuable part played by western irrigation in our food production program, have faith in its future and are willing to back new development with either federal government financing or purchase of sound irrigation district securities.

There is also the question of maintaining an adequate supply of wool, lambs and beef animals for the steadily increasing population of this country. Western reclamation has an indispensable role to play in this connection. We now import about one-half of our wool requirements. Our imports of beef cattle have risen from 172,910 head valued at $4,654,943 in 1925 to 492,609 head valued at $19,972,192 in 1929. These live cattle imports during recent years have taken practically every animal available in Mexico and Canada, and we would have imported hundreds of thousands from Argentina except for the quarantine on account of foot and mouth disease. Furthermore, after importing the nearly 500,000 head of live cattle in 1929, we were still short of beef and veal; consequently we imported 128,089,183 pounds of canned, chilled and frozen beef and veal. Compare such situation with that prevailing twenty-five years ago in 1904. In that year we exported 593,000 live cattle and 414,902,000 pounds of beef and veal or not far from the equivalent of 1,500,000 head of cattle. The question may well be asked as to where the beef, veal and wool requirements for this nation are to come from in 1940 with twenty million additional consumers. As demand for this class of product increases, the country has become accustomed to look toward the western horizon, for it has always been from the great range areas of the Mountain and Pacific Slope states that a large portion of our supply of these products has originated, but if these supplies are to be increased, the area of land irrigated must be expanded and expanded rapidly since the large limiting factor in connection with complete utilization of range areas in western United States is late fall and early spring pasture and available feed for wintering breeding stock in the irrigated valleys at lower altitude within trailing distance from the range. Alfalfa hay, beet tops, pulp and molasses, together with barley and oats constitute such feed for wintering, but it takes irrigated land in this section to produce these crops.



Irrigation pumping with electric power

A situation which should further lend hope to the western reclamationist who is appraising the probable local demand for his products, but which on the other hand should cause grave concern on the part of the consuming public on the Pacific Coast, is growth in the westbound shipments of hogs and dressed pork products. In 1929, 9,727 carloads of live hogs or approximately 875,400 head were moved into California by common carriers for slaughter. This is 55 per cent of all of the live hogs slaughtered in the state. These shipments largely originated in states east of the Continental Divide. They did not come in very large numbers from states on the coast to the north because a similar situation exists in Washington and Oregon livestock markets. Oregon received 29 per cent of its slaughter hogs from Idaho; 9 per cent from Montana and 6 per cent from North and South Dakota. Livestock markets in the state of Washington received 250,000 head of hogs from outside the state and in addition imported 12,000,000 pounds of green, frozen and cured pork products. These importations were largely from Montana, North and South Dakota and Nebraska. The Pacific Coast consumer of pork and pork products, therefore, appears likely for some time to pay the Middle West price plus carrying charges from Missouri River markets, and the local producer in the West is selling in a market protected by what is in effect a tariff wall measured by freight rates. The railroads are not complaining of this situation for we need and appreciate this westbound tonnage, but it is an indication of a handicap to development which is steadily gaining ground as population mounts without simultaneous growth of irrigated area.

Finally, to sum up the situation, if we are going to assume that good markets, good prices and fair profits depend upon a constant, vigorous demand, it would seem that the western farmer occupies a secure position in the future. Phenomenal population growth on the Pacific Coast assures the irrigation farmer of a local market on many staple products far greater than he can fill at prices exceeding those which prevail in the Middle West. He is also assured of an active demand for feed crops in valleys adjacent to areas suitable only for range sheep and cattle enterprises. He is finally assured of increasing demand in the Middle West and East for specialty crops which this area is particularly endowed by nature to produce provided quality is maintained and skillful merchandising is practiced. Actually there is reason to feel concern as to whether irrigated areas can be expanded with sufficient rapidity to meet the demand for irrigated farm products. Irrigation projects, particularly the large, difficult ones, require many years for the completion of surveys, economic and engineering, for construction of reservoirs, canals and other structural works and additional years for securing sound settlement. It apparently requires 8 to 10 years in the case of small projects and 20 to 25 years in the case of large projects before construction is completed, settlement secured and they have found themselves agriculturally and are making any substantial contribution of farm products beyond their own horizon.

As we consider the tremendous cost of constructing the projects of the future, there is a growing conviction that hydroelectric development must go hand in hand with expansion of irrigated land. Together they can lift the burden of construction costs which neither could bear alone. Since production of electrical energy is futile unless it also can be marketed profitably, we have a second tie-up between the growth of agriculture and industry in this part of the country. It is going to require far-sighted statesmanship at Washington, forward-looking business acumen on the part of western financiers and an abiding faith in the future agriculturally and industrially of the

Pacific slope to begin construction of great, joint irrigation-hydroelectric projects in anticipation of a market at the time of ultimate completion for the agricultural products of the land and the power created. If this faith is not evidenced by beginning new projects in the near future and rehabilitating sound ones now in difficulty, the West is going to be left sitting beside the road while other parts of the country capitalize on its natural opportunities. As a typical illustration, the great irrigation project which has been planned for the so-called Columbia Basin area is in many circles considered an idle dream, but it is a project absolutely essential to the future growth and development of the states of Idaho, Oregon and Washington. The ultimate area considered susceptible of successful irrigation in this project is, roughly, 1¾ million acres. The cost of providing each acre with an adequate water supply is figured at from $150.00 to $200.00 per acre, if no allowance is made for meeting a portion of the burden of construction through sale of power generated at the several damsites. It is, of course, a staggering thought to visualize either the construction of the whole project as a unit, or the settlement of so vast a tract in a few years, or the development of marketing facilities and markets for the avalanche of products produced, if the 1¾ million acres simultaneously came into production, but no sane man considers that development of this project would come in that way. If finally authorized, it will unquestionably be on the basis of development in several units with power as important a consideration as agricultural products and bearing a proportionate burden of the cost. The lands of these units would be slowly settled and very gradually would come into full production. The most optimistic proponents of the project feel that after authorization, 25 years would be required for the project to get under reasonable head. If deductions can be drawn from a comparison with the rate of construction, settlement and production program of the so-called Yakima Valley, 50 years would be a better figure than 25 years. At least long before the project would come into full flower of production of power and agricultural products, both will find that a market has been provided through natural industrial development and population growth in the North Pacific coast country.

I am fully aware of the difficulties experienced in merchandizing farm lands and in colonizing western reclamation projects as I have had a firsthand experience with this problem. I am increasingly impressed with the comparative ease with which families can be moved to the Inter-Mountain and Pacific slope country as compared with the task of moving them to the western great plains area. One works "with the wind," as it were, in establishing folks on land west of the mountains. The attractive living conditions and soft climate exert a pull that to my mind is steadily on the increase. Once uprooted, a settler nowadays oscillates around this whole United States in a little old Ford, listens and looks and finally lights where the fishing is good, the scenery captivating and the climate mild. I would not say that these considerations were placed ahead of opportunity to make a livelihood, but they certainly go with it hand in hand. It is surprising how many settlers or members of their family have poor health and must be located where they will not have to undergo climatic hardship or be forced to exert much physical energy. Circumstantial evidence of this tendency of settlers recently to flutter down to a location on the Pacific slope is found in the figures on increase in the number of farms in the various states 1930 as compared with 1920. The United States as a whole showed a decline of 2.3 per cent in number of farms, yet California had an increase of 16 per cent; Oregon, 10.1 per cent; Washington, 7.6 per cent; Nevada, 8.7 per cent; Utah, 5.4 per cent; Arizona, 32.9 per cent. Idaho alone of all the Pacific slope states showed a decline and that only amounted to 1 per cent.

It is too early to state whether the industrial depression will jar loose a large number of heads of families employed in industry and who will be forced to return

Cultivating asparagus with tractor and disk cultivator

to the land for a permanent livelihood, but I am convinced that in a year or two we will see such a movement although just when it will come and how extensive it will be depends upon the character of the recovery made by industry. It is all very well for present farmers to plead that there are too many now in the business of farming and that the movement should continue to be from the ranks of the producer to the consumer, but it is a question of a place to eat and sleep for hundreds of thousands who were sucked into industry during its expansion since the war and are now in the ranks of the unemployed. The farm looks like a meal ticket, even if it does not look attractive as an opportunity for making money, and daily there are more men looking for a place to light where a meal ticket is assured and less looking for the bright lights, short hours and high wages. The middlewestern farm lads in their twenties who abandoned the farm for the city during and immediately after the war and many of which are now in the ranks of the unemployed, find themselves now with a wife and family, their hair graying and with complete disillusionment as to ability to consistently make and save money in the city. In spite of the dismal picture painted of the farm situation, do not think that many such men will not be prospective farm settlers and that they will not have an eye on the West. They lack the capital to start up in the farming sections of the Middle West and are consequently thinking of a small tract of land, irrigated or otherwise, on the Pacific slope where it is rumored that a man can starve to death longer and like it than anywhere on the globe. We have found in our immigration work that the satisfied settler is the most effective advertisement for a country. The letter he writes back to his friends and relatives is still the most potent form of settlement advertising.

Western reclamation will always have its problems—to that extent it will not differ from agriculture elsewhere or with industry or transportation—but there is ample reason for believing that they will not be as difficult as those with which we are now confronted. Each year we are adding greatly to our knowledge of the technique of irrigated agriculture and the economic factors necessary for its ultimate success. There is nothing static about agricultural production. It is as migratory as industry, shifting with population growth, changes in human food and clothing requirements, transportation facilities and new developments in preservation and refrigeration, but of this we can be confident, western reclamation has unique advantages in production of certain agricultural commodities and if we are to maintain our present position in our natural markets, we must keep ahead of, certainly abreast of demand. I assert that a program of bringing in more irrigated lands in anticipation of the demands of a growing country is and will be for many years to come sound economics for the west.

Reclamation and Development in the Sacramento-San Joaquin Delta[1]

By George A. Atherton[2]

THE Sacramento-San Joaquin (California) Delta is a 400,000-acre triangle of low peat and sedimentary land, lying roughly between a point on the west where the two rivers flow into Suisun Bay, a northern point just south of the city of Sacramento, and a southern point near the Southern Pacific Railroad crossing over the San Joaquin River south of Stockton.

About half of this land is sedimentary, and above the level of ordinary high tides, but none of it is as much as 10 feet above mean sea level. All of the peat land is below the level of ordinary high tides, the greater portion of it being materially below the level of low tides. It is all accessible by means of a network of navigable channels, both natural and artificial, which provide excellent shipping facilities to Suisun and San Francisco bays with their bordering towns and cities. Practically all of these lands are now reclaimed, in units varying from a few hundred to twenty thousand acres.

Reclamation history of the area runs back to 1850, when the United States turned the lands over to California, with an obligation to reclaim them. The state turned them over to private owners, with the same obligation, and passed reclamation district legislation aimed to speed the work. For forty some years, however, all efforts to reclaim this swamp resulted in failure after failure, due to flood waters, particularly on the Sacramento River, and to the fact that the peat levees dried out and settled too rapidly for the hand and wheelbarrow method used in their construction.

It may be said that the beginning of successful reclamation came when the clam shell dredger was developed. Previous to this different types of dredgers had been used more or less in levee construction but with indifferent success. The clam shell dredger solved the problem; and it may be of interest to note that the present clam shell dredgers generally used in levee construction are essentially the same as those that were built in the early nineties. In fact there are still in successful operation in this delta clamshell dredgers that were in use in about 1892 and that have in them the original machinery. There has been no obsolescence of these clamshell dredgers because of later improved types. They disappear only from old age and hard work. They are all of the floating type; the earlier ones being built with booms 60 to 70 feet long. Now some are put out with booms of 225 feet and more in length.

It was with these machines that practically all of the present levees in this territory were constructed. The old scraper levees were enlarged and raised to three, four and more times their original dimensions and corresponding borrow cuts were made which largely increased the stream capacities. Old channels have been enlarged and additional channels excavated to further increase the stream capacities. The major project of these enlargements is the opening of the lower end of the Sacramento River by the federal government; a project that is costing several millions of dollars.

Experience has developed the fact that the peat lands could never have been successfully reclaimed except with these clamshell dredgers which made it possible to place in the levees material obtained from borrow pits 150 to 200 feet and more wide, excavated in some instances 40 feet and more deep below the original surface and all below the level of high tide. As explained before the peat in the levees shrunk; the foundation and the levees compressed as material was added. This was not all completed at once. It was necessary to add the material to the levees in stages with intervals of several months to enable the preceding one to stabilize. Even now after 20 years and more since the first closures, the levees continue to settle in places and periodic additions are necessary. The peat within these levees, as it dried out, rapidly shrunk, settled and decayed and in a very short time they were below the level of low tide. Now after years of reclamation, cultivation and occasional burning (all of this peat being highly inflammable when dry) much of this area is more than 6 feet below low tide.

Cross-sections show that in many places the volume of excavation from the borrow pit is ten times more than the corresponding cross-section of the levees above the

[1]Paper presented at a joint meeting of the Land Reclamation Division and the Pacific Coast Section of the American Society of Agricultural Engineers at San Francisco, January 1931.
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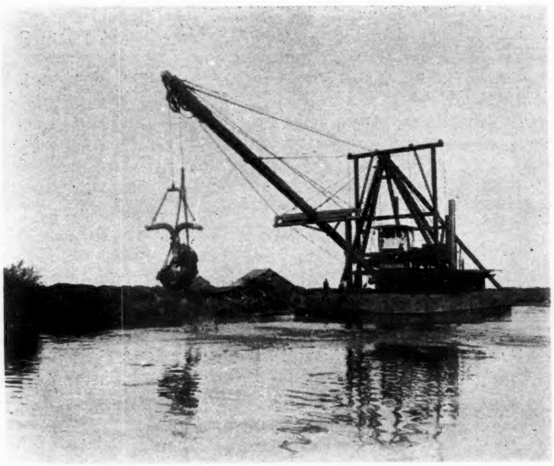

Typical clamshell dredger used in the delta operations

Newly added material on a levee. Dredge at work in the background

Sacked onions which were grown on delta peat land. This view gives some idea of the productivity of this land when properly drained and irrigated. Other crops which it produces successfully include Indian corn, beans, potatoes, barley, celery, mint, alfalfa and asparagus

surface of the ground. Notwithstanding all this, nearly all of these peat levees are in a fairly stable condition, with a reasonable elevation above high water and strong enough to withstand the high waters of the past.

Completion of the levees, however, did not complete the initial work necessary for the successful development of the lands behind them.

In the earlier developments no attention was paid to drainage. It soon developed that it was only in dry years and on the higher lands that farming could be carried on successfully. Shallow ditches were dug leading from the higher to the lower lands, sacrificing the lower lands to make it possible to farm the higher. This continued for many years. Then an occasional steam pump plant was put in with small ditches leading to it and without the remotest knowledge or consideration of the necessary capacity of the pumps or the ditches for proper drainage. Gradually this condition changed. More and larger pumping plants commensurate with the needs were installed. Immense canals with the necessary feeders were excavated until now excellent drainage is almost universal and is obtained by the use of electric power and centrifugal pumps. Practically all drainage is accomplished by pumping because the tidal waters are generally above the level of the land, preventing any drainage by gravity.

During the earlier period of the reclamation of these lands no consideration was given to irrigation. While the levees were small there was much seepage through them onto the land. The problem was to keep the land dry enough to successfully farm it, and no irrigation was necessary. As the levees were enlarged and compacted the seepage was reduced; the lands, except during seasons of heavy rainfall, dried out and it became apparent that irrigation was necessary if the best results were to be obtained from farming operations. The situation was just the reverse of that in the average irrigation district. In the latter the irrigation came first and the drainage later. In the delta reclamations the drainage came first and the irrigation later. The supply of water for this irrigation is obtained from the rivers through the network of channels lying immediately outside of the levees. A very large proportion of this irrigation is done by gravity because the lands are generally below the level of the sea. The peat portion of the delta where the land is below the level of low tide is irrigated entirely by gravity. In the higher, sedimentary portions of the delta pumping under a low head is necessary.

The irrigation conditions in this territory are unique. There is no irrigation system or project in the usual sense of a system. Each landowner fronting on the levees has his own water supply; develops it in his own way; operates it at his own expense; and finally discharges the excess or waste water into the reclamation district canals from which it is pumped by the district. The irrigation of the greater part of this 400,000 acres is handled in this way. It is so simple that the farmer can have no complaint against any one but himself if he does not get all of the water he wants and at the exact time when he needs it.

The foregoing constitutes the picture of the physical development of these lands down to the present time, on which the agricultural development, which is another story, has been based.

Breaking of the sediment lands was simple and not different from the breaking of sediment land anywhere. Breaking of the peat lands, however, was different and much more difficult. After the land was reclaimed and dried out the surface consisted, for a depth of about 18 inches, of swamp grasses and tule partly alive and partly dead but not decomposed. The mass was so loose in texture that it would not support a man's weight, much less the weight of a horse. This condition made the breaking of these lands a slow process, tedious and expensive. Horses were equipped with special shoes made with a large flat, iron ring about 12 inches across, radially ironed to the ordinary horse shoe and making a support somewhat like a bear-paw snowshoe. Even with this equipment it was a common occurrence to see horses bogged to their bodies. The lands in this way were finally conquered and with the coming of the modern track-type tractor the breaking and cultivating problems have been solved, although occasionally these get down so that all that shows above ground is the hat of the operator.

By intensive cultivation the land is quickly put into perfect shape for all classes of crops. Decomposition of the vegetable matter progresses rapidly with alternating exposure to water, drought and air. At the end of the second year of cultivation the soil is in a condition that resembles the soil in a country back yard chip heap where the household wood has been cut for years.

This, briefly, is the story of the reclamation and development of this wonderfully fertile area through a period of about 70 years. The pioneers have all passed out of the picture and many of their successors have also gone. The work of reclamation and development has progressed through two generations and is still incomplete. However, it has reached a point where all of the lands are intensively cultivated, well irrigated and producing a volume and variety of crops perhaps unsurpassed in any equally compact area of land in the United States.

Many of these crops are common to both the peat and sediment areas. Others do not thrive equally well. The sediment lands successfully grow the deciduous fruits common to the two great valleys; the peat lands are not suited to their production. Indian corn grown for grain purposes is particularly a crop of the peat lands. More than 90 per cent of California's total production of this class of corn is grown there. From 10,000 to 12,000 acres per year, on the average, are devoted to this crop.

Important crops common to both areas are sugar beets, of which more than 20,000 acres were grown this last year; onions, beans, potatoes, barley, celery, mint, alfalfa and asparagus. The latter, from a national aspect, is the most important of all. Probably 95 per cent of the canned asparagus consumed in the United States is produced and canned in this delta and many thousands of cases are shipped from it to foreign countries.

Enormous quantities of all of these crops are grown in this delta with a total value, dependent on the markets, of twenty-five to thirty millions of dollars. They represent one of the greatest localized agricultural assets of California.

Temperatures of Peat Soil Relative to Summer Frost Control[1]

By H. B. Roe[2], J. H. Neal[3], B. R. Colby[4] and B. C. Colby[5]

(Concluded from the March number)

RELATION OF BAROMETRIC TRENDS TO TEMPERATURE TRENDS

In this part of the study, as the only barometric record available was that at Minneapolis, the maximum and minimum temperature records both at the peat plots and at the Minneapolis weather station were compared with the barometric pressure records already discussed, as a safeguard to reliability of deductions made from the comparison.

Separate charts of the barometer readings for 4:00 a.m., 12:00 noon, and 6:47 p.m., with the vertical scale inverted, were each compared with the charts of the daily minimum temperatures for the same year both for Minneapolis and for the peat plots. But as the 6:47 p.m. barometric pressures showed as close an agreement with the minimum temperature as did either of the other sets of daily readings, the barometric charts for 4:00 a.m. and at 12:00 noon are not further considered, and henceforth the chart for 6:47 p.m. is the only barometric record especially referred to in this paper. It is shown along with the humidity chart above those for the minimum and maximum temperatures in each of Figs. 3 to 8.

For each season at each station those days were especially noted where the minimum temperatures dropped to quite low levels. Against these are tabulated the averages of the barometric pressures, separately computed, for each season, for the days before these days of low minimum temperature and for the days of the low minima, as well as the general average in each case for all three seasons (Table VII).

As a general rule, on the days preceding low minimum Minneapolis temperatures the barometric pressure is slightly lower than it is on the days when the low minimum temperatures occur; but both on the days before and on the days of the occurrence of low minimum temperatures at the peat plots, the averages of the barometric pressures are equal, and they are somewhat higher than the average pressure at Minneapolis not only for each of the three separate seasons but also for the general average of the three seasons. Hence, it does not seem that the trend of barometric pressure as determined by seasonal averages for any given temperature condition is a reliable index by which alone to foretell the approach of a low minimum temperature.

However, this evidence should not hastily be assumed as conclusive because inspection of Figs. 3 to 8 shows that there is an approximate agreement between the curves of the minimum temperatures and the inverted curve of the barometric pressure for the same year. Furthermore, the general summary at the close of this paper and itemized in Table XXIII, showing the meteorological condition actually preceding and attending freezing temperatures at the peat plots does definitely sustain the trend of barometric pressure as an index of impending frost.

It is of general interest also to note that the curves of maximum temperatures show a similar tendency to agree with opposite trends in the barometric curve.

GENERAL TRENDS OF HUMIDITY

In the consideration of relative humidity in relation to temperature trends the daily humidity records for the Minneapolis weather bureau station (taken at 6:47 p.m.) are the main basis of the study in all three seasons, but for 1929 the average of humidity records obtained from the recording psychrometers at Stations 3 and 5 on the experimental tract are also considered. Averaging the records of these two stations does not introduce any appreciable error or variation, as the records for the two were substantially the same during the season. The average of the Minneapolis readings for the period from May 16 to October 15, inclusive, for each of the three years, and the average of the records on the experimental tract for the same period in 1929, are shown below:

Relative Humidity	1927	1928	1929
Average for season—Minneapolis (6:47 p.m.)	57.0	54.0	51.6
Average for season—experimental tract (6:00 p.m.)			60.5

The higher average humidity on the plot for 1929 is probably due largely to three differences of local conditions between the Minneapolis station and that of the experimental tract. At the latter place the records were taken near the peat surface which was moist during most of the season. Lake Minnetonka and several marsh areas are close to the tract, and there was vegetation growing all around the stations at which these humidity records were taken. The Minneapolis records, on the other hand, are taken on top of a city office building surrounded by

[1]Journal Series Paper No. 1005 of the Agricultural Experiment Station, University of Minnesota. (The first installment was published in the March issue.) Released for first publication in AGRICULTURAL ENGINEERING. The full title of this paper is "A Study of the Influence of Various Meteorological Factors and of Drainage on Air and Surface Temperatures on Peat Soil with Especial Reference to Forecasting of Summer Frosts."

[2]Professor, in charge of reclamation activities, University of Minnesota. Mem. A.S.A.E.

[3]Department of Agricultural Engineering, University of Minnesota. Assoc. Mem. A.S.A.E.

[4,5]Senior students (1930) in agricultural engineering, University of Minnesota. Student assistants on this project in the Minnesota Agricultural Experiment Station. Student Mems. A.S.A.E. (Most of the actual work on this project was done and the entire original papers on it were written by them).

TABLE VII
AVERAGES OF BAROMETRIC PRESSURES RELATIVE TO MINIMUM TEMPERATURES

Weather Station	1927	1928	1929	Ave. 3 Seasons
For Season - Minneapolis	28.95	28.93	28.98	28.95
For days before Minneapolis lows	28.99	28.84	29.06	28.97
For days of Minneapolis lows	29.11	28.97	29.08	29.05
For days before Peat Plot lows	29.04	28.97	29.01	29.01
For days of Peat Plot lows	29.07	28.98	28.99	29.01

TABLE VIII
BAROMETRIC PRESSURES RELATIVE TO HUMIDITY CONDITIONS

Year	Barometric Pressure when Humidity is High	Medium	Low
1927	28.99	28.98	28.98
1928	28.84	28.95	28.89
1929	28.91	28.94	29.06
Ave. 3 Seasons	28.91	28.96	28.98

TABLE IX
AVERAGES OF RELATIVE HUMIDITIES AT TIMES OF TEMPERATURE LOWS
(Per cent of Total Number of Readings)

Sets Averaged	1927	1928	1929	Ave. 3 Seasons
Minneapolis Station				
All 6:47 p.m. readings for the season	56.98	54.00	51.57	54.18
Lows at 6:47 p.m. on days of low temperature only	54.05	44.67	45.45	48.06
Lows at 6:47 p.m. on days before low temperatures	56.89	56.53	50.65	54.69
For clear days at time of low temps. (about 4 a.m.)	47.20	48.00	45.50	47.90
All lows at time of low temps. (about 4 a.m.)	56.00	51.70	46.80	51.50
Peat Plot Stations				
Lows at 6:47 p.m. on days of low temperature only	46.10	44.05	42.06	44.07
Lows at 6:47 p.m. on days before low temperatures	47.20	44.77	48.12	46.70
For clear days at time of low temps. (about 4 a.m.)	47.40	47.60	45.30	46.80
All lows at time of low temps. (about 4 a.m.)	47.00	44.20	45.00	45.10

TABLE X
AVERAGE HUMIDITY CORRESPONDING TO AVERAGES OF TEMPERATURE EXTREMES

Humidity Condition	Maximum Temperatures				Minimum Temperatures			
	1927	1928	1929	Ave. 3 Seasons	1927	1928	1929	Ave. 3 Seasons
High	67.1	79.9	79.3	73.2	53.0	57.4	55.6	55.3
Medium	74.3	75.8	76.1	75.4	55.3	56.4	56.1	55.9
Low	75.8	71.9	80.5	76.1	54.6	50.0	59.7	54.8

TABLE XI
DISTRIBUTION OF CLOUDINESS CLASSES
(Per cent of all Days)

Minneapolis					Chaska				
Cloudiness Class	1927	1928	1929	Ave. 3 Years	Cloudiness Class	1927	1928	1929	Ave. 3 Years
Clear-clear	28.1	33.3	28.1	29.8	Clear	30.7	48.4	50.7	43.3
Cloudy-clear	20.9	17.0	20.3	19.4	Partly cloudy	36.7	30.7	32.6	33.3
Clear-cloudy	9.8	13.1	15.7	12.9					
Cloudy-cloudy	41.2	36.6	35.9	37.9	Cloudy	32.6	20.9	16.7	23.4
Totals	100	100	100	100		100	100	100	100

mineral soil, with no vegetation of any sort adjacent to the place.

INFLUENCE OF PRECIPITATION ON HUMIDITY

In 1927 there were 19.9 inches of precipitation during the observation period, but most of this rainfall came in a few heavy rains, although at the end of the season several light showers occurred. Short periods of heavy precipitation, however, seem to have had but little effect on the average humidity throughout a month or season. The humidity for the first part of the season of 1927 averaged slightly below normal which is 57 for the observation period. However, during September and the first half of October, the humidity stayed consistently high, so much so in fact that the seasonal average was considerably above that of the other two years. On September 6 to 9 the weather was cloudy, and the humidity was above 80 per cent at 6:47 p.m. each day. Moreover, on September 24 it went up above 50 per cent and did not fall below this figure for the rest of the season.

In 1928 conditions were quite different. In this year there were 17.3 inches of rain, but with the exception of a dry period in the last half of May and the first week of June, this quantity was well distributed in moderate showers throughout the season. These showers frequently sent the relative humidity up to high percentages, but there was little tendency for such a percentage to be maintained for more than a day or two. Consequently the season was one characterized by many sharply contrasted extremes of humidity. This type of variation is not, however, as this case shows, productive of very high averages over a long period of time.

In 1929 the humidity did not show the same tendency to frequent extremes that it did in the previous year. Neither were there long periods of departure from the normal, but the humidity clung quite consistently to the average value for the entire season. The variations were, in the main, merely short time fluctuations oscillating through the normal. The total precipitation in 1929 did not vary much from that of the first two seasons, being 18.7 inches. It was distributed rather evenly throughout the season occurring in all types of rains ranging from several small showers up to one 2.5-inch rain.

The extremes of humidity occurring in any season seem to have quite definite limits. In each of the years studied the lowest reading fell between 20 and 25 per cent and the highest between 95 and 100 per cent. A humidity of nearly 100 per cent seems to be possible at almost any time. A reading of less than 25 per cent, however, seems to be most apt to occur in May or early June, although one such reading occurred on July 22, 1929. The greatest observed range within 24 hours was a change of 54 per cent which occurred once as a rise from 6.47 p.m. on August 15, 1927, to the same time next day, and once as a fall from the reading on September 9 to that on September 10, 1929.

A study of the psychrometer records from the experimental tract shows that, in spite of the wide range of humidity, there is, with the exception of times when precipitation occurs, a definite tendency for the humidity to change in a regular order throughout each day. As is to be expected, the humidity at night usually is quite high. When the sun comes up, it falls rapidly and continues to fall as long as the temperature rises. The humidity is, therefore, lowest during the heat of the day. When the temperature begins to fall the humidity starts rising, but usually remains quite low until sunset, at which time it rises rapidly for an hour or so. After this evening rise a rather stable percentage is reached from which there are but minor fluctuations, the tendency being, however, for a slow rise throughout the night.

While only general conclusions may be drawn from these records, it appears that aside from the daily cycle, the humidity does not show any inclination to move in a cyclic manner. A heavy rain does not seem to be of much importance in changing the relative humidity except for a short time. However, several small showers coming along on consecutive days have a large influence on the average. Any kind of a rain at any time may raise the relative humidity to above 90 per cent.

RELATION OF RELATIVE HUMIDITY TO BAROMETRIC AND TEMPERATURE TRENDS

In the study of these relations three divisions based on conditions of relative humidity are considered as follows:

1. Low humidity—relative humidity below 40 per cent
2. Medium humidity—relative humidity 40 per cent or below 65 per cent (average, 57 per cent)
3. High humidity — relative humidity 65 per cent or more.

Table VIII gives the average barometric pressures for each condition of humidity for each season as well as the averages for the three seasons combined. The average for the three years shows a slight tendency for the barometric pressures to increase as the relative humidity lowers. However, this does not appear to be a usual relationship as it holds in only one of the individual years.

Using as temperature lows only the lowest points reached in each cold spell it was sought to determine the behavior of the relative humidity with respect to these extreme temperature lows. The relative humidity at the time of these temperature lows was found approximately by drawing a smooth curve through the points of known humidity and taking from this curve the relative humidity at about 4:00 a.m. (the average time of daily minimum temperatures). The results obtained are shown in Table IX. These data show that, at the time of the temperature

lows, generally the humidity is usually about the same as it is at the same time of the day on clear days. That is, the humidity is not generally lower than usual when the low minimum temperatures occur. At Minneapolis, the humidity at 6:47 p.m. the nights before low minimum temperatures occur at that station is not lower than the average for the season, while it is generally lower both on the nights before and the days of the temperature lows at the peat plots. It appears, therefore, that the relative humidity does not definitely forecast those nights when low minimum temperatures are about to occur.

Using the three established divisions of relative humidity, the extreme temperature averages under conditions of high, medium, and low relative humidity for each season, appear in Table X. This table again shows a lack of any definite relationship of temperatures to relative humidity conditions. Under high humidity the maximum temperature was low, but this was not especially true of the minimum temperature, although Table XXIII shows low humidities occurring the day before freezing temperatures more times than it does high humidities.

GENERAL WEATHER CONDITIONS AS TO CLEARNESS, CLOUDINESS, ETC., IN RELATION TO TEMPERATURE

The records of the amount of cloudiness at sunset and at sunrise at the Minneapolis weather station justify the division into four classes from sunset one day to and including sunrise of the next day as follows:

1. "Clear-clear"—clear at both sunset and sunrise
2. "Cloudy-clear"—cloudy at sunset and clear at sunrise
3. "Clear-cloudy"—clear at sunset and cloudy at sunrise
4. "Cloudy-cloudy"—cloudy at both sunset and sunrise.

The daily general records of the Chaska station, as taken, consist of only one daily notation to describe the conditions of clearness and cloudiness reported under the three following subdivisions: (1) Clear, (2) partly cloudy, and (3) cloudy.

The percentages that each of the classes is of the total number of daily units for each one of the seasons are given according to both classifications in Table XI. From this table it is clear that the records at the two stations could not check each other at all closely. This probably is due very largely to the difference in the ideas of the two observers as to the measure of the degree of cloudiness and the different methods of reading, and recording it. At Minneapolis, for example, two definite daily readings are taken using a unit of time beginning one day and extending over a part of the next day; whereas at Chaska one reading only is taken for each calendar day, and this is considered to represent the general condition throughout the day rather than the amount of cloudiness at any specific time.

However, in some ways the two records show a significant agreement, for example: The longest Minneapolis record for which continuous clear readings were given was from sunrise August 7 to sunset August 14 (1928), inclusive, and this same period was the longest clear period recorded at Chaska, although there the time was one day shorter. There were two intervals of continuous cloudiness that lasted five days each. One began September 25, 1927, and the other started September 10, 1928. The longest period showing continuous cloudiness at the Minneapolis station was the eight-day period from sunset September 24 to the same time October 2, 1927. It appears, therefore, that the longest period of continuously clear or cloudy weather that may be expected to occur in three seasons is about one week in length.

One of the most striking effects of cloudiness is its power to restrain the minimum temperature from falling very low at night. A more important effect is its tendency to keep the maximum temperature from rising to high levels. The relation of cloudiness to low temperatures was studied in detail with the results shown in Tables XII and XIII. In interpreting these tables, it must be borne in mind that the record of cloudiness used in connection with the temperature lows at the peat plots is from the Chaska station where the notation is simply of the conditions typical of each day which conditions do not necessarily hold at any specific part of the day or through the entire day. At any rate they may not always be strictly representative of conditions at the peat plots. The temperature lows noted are merely the lowest minimum occurring in each cold spell, as these are considered representative of cold mornings. As the number of such mornings which could be selected from each season do not exceed from twenty to twenty-five, the number of instances falling in each classification is so small that considerable variations in the percentage results are to be expected.

From the part of Table XII referring to the peat plots, it is apparent that most of the extreme temperature lows occur on mornings of days classified as clear, less occur on partly cloudy, and the least on the cloudy mornings. The contrast is especially pronounced in 1928 and 1929. The percentages of the total number of times falling in each of the various classes with respect to cloudiness, on which lows occurred, is given in Table XIII. For the peat plots this table also shows quite uniformly in each of the years that extreme temperature lows are most apt to occur on clear, less apt to occur on partly cloudy, and least apt to occur on cloudy days.

The records of cloudiness at the Minneapolis station are of the conditions at sunset and at the following sunrise, but even they do not indicate when changes may have occurred between these times. Therefore, the classification for the Minneapolis records is somewhat different, as it depends upon whether the weather was clear or cloudy at sunset the evening before the extreme temperature low and at sunrise the morning of such low. Table XII shows that the results in the years 1927 and 1929 agree with each other, but 1928 was radically different. The fact that in 1927 and 1929 clear evening and clear morn-

TABLE XII
PROPORTION OF TIMES OF OCCURRENCE OF MINIMUM TEMPERATURES
COVERED BY THE VARIOUS DEGREES OF CLOUDINESS

Peat Plot Minimum Temperatures Compared with Chaska Cloudiness Record							Contemporary Minneapolis Record of Minimum Temperatures Compared with Mpls. Cloudiness Record							
Degree of Cloudiness	Percentage of Times of Occurrence of Minimum Temperatures						Degree of Cloudiness		Percentage of Times of Occurrence of Minimum Temperatures					
	Total Season			Average of Extreme Lows					Total Season			Average of Extreme Lows		
	1927	1928	1929	1927*	1928#	1929†	Evening	Morning	1927	1928	1929	1927*	1928‡	1929*
Clear	30.7	48.4	50.7	45.0	63.6	68.0	Clear	Clear	28.1	33.3	28.1	47.3	26.7	50.0
Partly Cloudy	36.7	30.7	32.6	35.0	27.4	28.0	Cloudy	Clear	20.9	17.0	20.3	21.1	40.0	25.0
							Clear	Cloudy	9.8	13.1	15.7	0.0	13.3	0.0
Cloudy	32.6	20.9	16.7	20.0	9.0	4.0	Cloudy	Cloudy	41.2	36.6	35.9	36.6	20.0	25.0

*20 low minimum days. † 25 low minimum days. # 22 low minimum days. ‡ 15 low minimum days.

TABLE IX
AVERAGES OF RELATIVE HUMIDITIES AT TIMES OF TEMPERATURE LOWS
(Per cent of Total Number of Readings)

Sets Averaged	1927	1928	1929	Ave. 3 Seasons
Minneapolis Station				
All 6:47 p.m. readings for the season	56.98	54.00	51.57	54.18
Lows at 6:47 p.m. on days of low temperature only	54.05	44.67	45.45	48.06
Lows at 6:47 p.m. on days before low temperatures	56.89	56.53	50.65	54.69
For clear days at time of low temps. (about 4 a.m.)	47.20	48.00	45.50	47.90
All lows at time of low temps. (about 4 a.m.)	56.00	51.70	46.80	51.50
Peat Plot Stations				
Lows at 6:47 p.m. on days of low temperature only	46.10	44.05	42.06	44.07
Lows at 6:47 p.m. on days before low temperatures	47.20	44.77	48.12	46.70
For clear days at time of low temps. (about 4 a.m.)	47.40	47.60	45.30	46.80
All lows at time of low temps. (about 4 a.m.)	47.00	44.20	45.00	45.10

TABLE X
AVERAGE HUMIDITY CORRESPONDING TO AVERAGES OF TEMPERATURE EXTREMES

Humidity Condition	Maximum Temperatures				Minimum Temperatures			
	1927	1928	1929	Ave. 3 Seasons	1927	1928	1929	Ave. 3 Seasons
High	67.1	79.9	79.3	73.2	53.0	57.4	55.6	55.3
Medium	74.3	75.8	76.1	75.4	55.3	56.4	56.1	55.9
Low	75.8	71.9	80.5	76.1	54.6	50.0	59.7	54.8

TABLE XI
DISTRIBUTION OF CLOUDINESS CLASSES
(Per cent of all Days)

Minneapolis					Chaska				
Cloudiness Class	1927	1928	1929	Ave. 3 Years	Cloudiness Class	1927	1928	1929	Ave. 3 Years
Clear-clear	28.1	33.3	28.1	29.5	Clear	30.7	48.4	50.7	43.3
Cloudy-clear	20.9	17.0	20.3	19.4	Partly cloudy	36.7	30.7	32.6	33.3
Clear-cloudy	9.8	13.1	15.7	12.9					
Cloudy-cloudy	41.2	36.6	35.9	37.9	Cloudy	32.6	20.9	16.7	23.4
Totals	100	100	100	100		100	100	100	100

mineral soil, with no vegetation of any sort adjacent to the place.

INFLUENCE OF PRECIPITATION ON HUMIDITY

In 1927 there were 19.9 inches of precipitation during the observation period, but most of this rainfall came in a few heavy rains, although at the end of the season several light showers occurred. Short periods of heavy precipitation, however, seem to have had but little effect on the average humidity throughout a month or season. The humidity for the first part of the season of 1927 averaged slightly below normal which is 57 for the observation period. However, during September and the first half of October, the humidity stayed consistently high, so much so in fact that the seasonal average was considerably above that of the other two years. On September 6 to 9 the weather was cloudy, and the humidity was above 80 per cent at 6:47 p.m. each day. Moreover, on September 24 it went up above 50 per cent and did not fall below this figure for the rest of the season.

In 1928 conditions were quite different. In this year there were 17.3 inches of rain, but with the exception of a dry period in the last half of May and the first week of June, this quantity was well distributed in moderate showers throughout the season. These showers frequently sent the relative humidity up to high percentages, but there was little tendency for such a percentage to be maintained for more than a day or two. Consequently the season was one characterized by many sharply contrasted extremes of humidity. This type of variation is not, however, as this case shows, productive of very high averages over a long period of time.

In 1929 the humidity did not show the same tendency to frequent extremes that it did in the previous year. Neither were there long periods of departure from the normal, but the humidity clung quite consistently to the average value for the entire season. The variations were, in the main, merely short time fluctuations oscillating through the normal. The total precipitation in 1929 did not vary much from that of the first two seasons, being 18.7 inches. It was distributed rather evenly throughout the season occurring in all types of rains ranging from several small showers up to one 2.5-inch rain.

The extremes of humidity occurring in any season seem to have quite definite limits. In each of the years studied the lowest reading fell between 20 and 25 per cent and the highest between 95 and 100 per cent. A humidity of nearly 100 per cent seems to be possible at almost any time. A reading of less than 25 per cent, however, seems to be most apt to occur in May or early June, although one such reading occurred on July 22, 1929. The greatest observed range within 24 hours was a change of 54 per cent which occurred once as a rise from 6.47 p.m. on August 15, 1927, to the same time next day, and once as a fall from the reading on September 9 to that on September 10, 1929.

A study of the psychrometer records from the experimental tract shows that, in spite of the wide range of humidity, there is, with the exception of times when precipitation occurs, a definite tendency for the humidity to change in a regular order throughout each day. As is to be expected, the humidity at night usually is quite high. When the sun comes up, it falls rapidly and continues to fall as long as the temperature rises. The humidity is, therefore, lowest during the heat of the day. When the temperature begins to fall the humidity starts rising, but usually remains quite low until sunset, at which time it rises rapidly for an hour or so. After this evening rise a rather stable percentage is reached from which there are but minor fluctuations, the tendency being, however, for a slow rise throughout the night.

While only general conclusions may be drawn from these records, it appears that aside from the daily cycle, the humidity does not show any inclination to move in a cyclic manner. A heavy rain does not seem to be of much importance in changing the relative humidity except for a short time. However, several small showers coming along on consecutive days have a large influence on the average. Any kind of a rain at any time may raise the relative humidity to above 90 per cent.

RELATION OF RELATIVE HUMIDITY TO BAROMETRIC AND TEMPERATURE TRENDS

In the study of these relations three divisions based on conditions of relative humidity are considered as follows:

1. Low humidity—relative humidity below 40 per cent
2. Medium humidity—relative humidity 40 per cent or below 65 per cent (average, 57 per cent)
3. High humidity — relative humidity 65 per cent or more.

Table VIII gives the average barometric pressures for each condition of humidity for each season as well as the averages for the three seasons combined. The average for the three years shows a slight tendency for the barometric pressures to increase as the relative humidity lowers. However, this does not appear to be a usual relationship as it holds in only one of the individual years.

Using as temperature lows only the lowest points reached in each cold spell it was sought to determine the behavior of the relative humidity with respect to these extreme temperature lows. The relative humidity at the time of these temperature lows was found approximately by drawing a smooth curve through the points of known humidity and taking from this curve the relative humidity at about 4:00 a.m. (the average time of daily minimum temperatures). The results obtained are shown in Table IX. These data show that, at the time of the temperature

lows, generally the humidity is usually about the same as it is at the same time of the day on clear days. That is, the humidity is not generally lower than usual when the low minimum temperatures occur. At Minneapolis, the humidity at 6:47 p.m. the nights before low minimum temperatures occur at that station is not lower than the average for the season, while it is generally lower both on the nights before and the days of the temperature lows at the peat plots. It appears, therefore, that the relative humidity does not definitely forecast those nights when low minimum temperatures are about to occur.

Using the three established divisions of relative humidity, the extreme temperature averages under conditions of high, medium, and low relative humidity for each season, appear in Table X. This table again shows a lack of any definite relationship of temperatures to relative humidity conditions. Under high humidity the maximum temperature was low, but this was not especially true of the minimum temperature, although Table XXIII shows low humidities occurring the day before freezing temperatures more times than it does high humidities.

GENERAL WEATHER CONDITIONS AS TO CLEARNESS, CLOUDINESS, ETC., IN RELATION TO TEMPERATURE

The records of the amount of cloudiness at sunset and at sunrise at the Minneapolis weather station justify the division into four classes from sunset one day to and including sunrise of the next day as follows:

1. "Clear-clear"—clear at both sunset and sunrise
2. "Cloudy-clear"—cloudy at sunset and clear at sunrise
3. "Clear-cloudy"—clear at sunset and cloudy at sunrise
4. "Cloudy-cloudy"—cloudy at both sunset and sunrise.

The daily general records of the Chaska station, as taken, consist of only one daily notation to describe the conditions of clearness and cloudiness reported under the three following subdivisions: (1) Clear, (2) partly cloudy, and (3) cloudy.

The percentages that each of the classes is of the total number of daily units for each one of the seasons are given according to both classifications in Table XI. From this table it is clear that the records at the two stations could not check each other at all closely. This probably is due very largely to the difference in the ideas of the two observers as to the measure of the degree of cloudiness and the different methods of reading, and recording it. At Minneapolis, for example, two definite daily readings are taken using a unit of time beginning one day and extending over a part of the next day; whereas at Chaska one reading only is taken for each calendar day, and this is considered to represent the general condition throughout the day rather than the amount of cloudiness at any specific time.

However, in some ways the two records show a significant agreement, for example: The longest Minneapolis record for which continuous clear readings were given was from sunrise August 7 to sunset August 14 (1928), inclusive, and this same period was the longest clear period recorded at Chaska, although there the time was one day shorter. There were two intervals of continuous cloudiness that lasted five days each. One began September 25, 1927, and the other started September 10, 1928. The longest period showing continuous cloudiness at the Minneapolis station was the eight-day period from sunset September 24 to the same time October 2, 1927. It appears, therefore, that the longest period of continuously clear or cloudy weather that may be expected to occur in three seasons is about one week in length.

One of the most striking effects of cloudiness is its power to restrain the minimum temperature from falling very low at night. A more important effect is its tendency to keep the maximum temperature from rising to high levels. The relation of cloudiness to low temperatures was studied in detail with the results shown in Tables XII and XIII. In interpreting these tables, it must be borne in mind that the record of cloudiness used in connection with the temperature lows at the peat plots is from the Chaska station where the notation is simply of the conditions typical of each day which conditions do not necessarily hold at any specific part of the day or through the entire day. At any rate they may not always be strictly representative of conditions at the peat plots. The temperature lows noted are merely the lowest minimum occurring in each cold spell, as these are considered representative of cold mornings. As the number of such mornings which could be selected from each season do not exceed from twenty to twenty-five, the number of instances falling in each classification is so small that considerable variations in the percentage results are to be expected.

From the part of Table XII referring to the peat plots, it is apparent that most of the extreme temperature lows occur on mornings of days classified as clear, less occur on partly cloudy, and the least on the cloudy mornings. The contrast is especially pronounced in 1928 and 1929. The percentages of the total number of times falling in each of the various classes with respect to cloudiness, on which lows occurred, is given in Table XIII. For the peat plots this table also shows quite uniformly in each of the years that extreme temperature lows are most apt to occur on clear, less apt to occur on partly cloudy, and least apt to occur on cloudy days.

The records of cloudiness at the Minneapolis station are of the conditions at sunset and at the following sunrise, but even they do not indicate when changes may have occurred between these times. Therefore, the classification for the Minneapolis records is somewhat different, as it depends upon whether the weather was clear or cloudy at sunset the evening before the extreme temperature low and at sunrise the morning of such low. Table XII shows that the results in the years 1927 and 1929 agree with each other, but 1928 was radically different. The fact that in 1927 and 1929 clear evening and clear morn-

TABLE XII
PROPORTION OF TIMES OF OCCURRENCE OF MINIMUM TEMPERATURES COVERED BY THE VARIOUS DEGREES OF CLOUDINESS

Peat Plot Minimum Temperatures Compared with Chaska Cloudiness Record							Contemporary Minneapolis Record of Minimum Temperatures Compared with Mpls. Cloudiness Record							
Degree of Cloudiness	Percentage of Times of Occurrence of Minimum Temperatures						Degree of Cloudiness		Percentage of Times of Occurrence of Minimum Temperatures					
	Total Season			Average of Extreme Lows			Evening	Morning	Total Season			Average of Extreme Lows		
	1927	1928	1929	1927*	1928#	1929†			1927	1928	1929	1927*	1928‡	1929*
Clear	30.7	48.4	50.7	45.0	63.6	68.0	Clear	Clear	28.1	33.3	28.1	47.3	26.7	50.0
Partly Cloudy	36.7	30.7	32.6	35.0	27.4	28.0	Cloudy	Clear	20.9	17.0	20.3	21.1	40.0	25.0
							Clear	Cloudy	9.8	13.1	15.7	0.0	13.3	0.0
Cloudy	32.6	20.9	16.7	20.0	9.0	4.0	Cloudy	Cloudy	41.2	36.6	35.9	36.6	20.0	25.0

*20 low minimum days. † 25 low minimum days. # 22 low minimum days. ‡ 15 low minimum days.

TABLE XIII
PROPORTION OF TIMES OF OCCURRENCE OF DIFFERENT DEGREES OF CLOUDINESS COVERED BY DAYS OF OCCURRENCE OF MINIMUM TEMPERATURES

Chaska Cloudiness Record Compared with Minimum Temperature Record at Peat Plots				Contemporary Minneapolis Record of Cloudiness Compared with Minimum Temperature Record at Minneapolis				
Degree of Cloudiness	Percentage of Days of Minimum Temperature Occurring under Given Degree of Cloudiness			Degree of Cloudiness		Percentage of Days of Minimum Temperature Occurring under Given Degree of Cloudiness		
	1927	1928	1929	Evening	Morning	1927	1928	1929
Clear	19.6	16.9	25.4	Clear	Clear	20.9	7.8	23.3
Partly Cloudy	12.7	12.8	16.3	Cloudy	Clear	12.5	23.1	16.1
				Clear	Cloudy	0.0	10.0	0.0
Cloudy	8.2	6.3	4.5	Cloudy	Cloudy	9.5	5.4	9.1

TABLE XIV
NUMBER OF MARKEDLY COLD MORNINGS FOLLOWING RAINS

Number of	1927	1928	1929	Ave. 3 Seasons
Rains considered	15	18	13	46
Days after rain	1st. 2d. 3d.	1st. 2d. 3d.	1st. 2d. 3d.	1st. 2d. 3d.
Markedly cold mornings	2 2 3	1 6 2	1 3 0	4 11 5

ing conditions gave the greatest percentage of extreme temperature lows, and showed the greatest percentage of such mornings that had lows; and that cloudy evening and clear morning, and cloudy evening and cloudy morning follow in both respects, tends to check the results obtained at the peat plots.

In contrast with this argument, while 1928 seems exceptional it is worthy of notice that the high percentage of extreme temperature lows occurring on the cloudy evenings and clear mornings is, probably a reasonable condition, for cloudiness the preceding afternoon might keep the temperature low, and if the sky cleared early in the evening, the conditions would be favorable for the temperature to drop sharply from its already low level, while contrariwise the small number of extreme temperature lows occurring on a cloudy morning following a clear evening is probably to be expected as the temperatures in such cases would be high ordinarily the evening before, and any cloudiness coming later would tend to prevent the temperature from running down. When a change of conditions occurs between evening and morning, the time of the change no doubt makes a great difference in the effect on the temperatures, but the data at hand do not cover this factor. It is possible that the nights indicated as cloudy may have been clear for a considerable portion of the time between the times of the evening and morning readings. The final summary and Table XXIII further clarify conclusions under this head.

THE RAINFALL RECORD AND ITS RELATION TO TEMPERATURE TRENDS

It is a matter of common observation that the temperature during a rain is usually cool, but is seldom very cold and almost never really warm. So the findings that rainfall throughout an afternoon results in a low maximum temperature for the day, and that a rainy night seems to keep the minimum temperature from falling very low, appear reasonable. In many cases rains occur in and often terminate a warm spell, as on September 3 and 4, 1929.

There is a noticeable tendency for a cold morning to come on the second day after a rain, although occasionally it appears on the first or third day after. In studying this trend, only those rains of one-fourth inch or over, and not followed by another such rain within the next two days, were considered. The precipitation records at the peat plots, and the minimum air temperatures on the one-foot control are used throughout in this study. The number of rains considered in each season, and the number of unusually cold mornings occurring within the first three days after rains are shown in Table XIV. Only mornings when the minimum temperatures fell below 40 degrees (Fahrenheit) are considered markedly cold mornings. Table XV indicates the same trend, as that just above noted, but in a slightly different manner.

It appears that the minimum temperatures usually drop

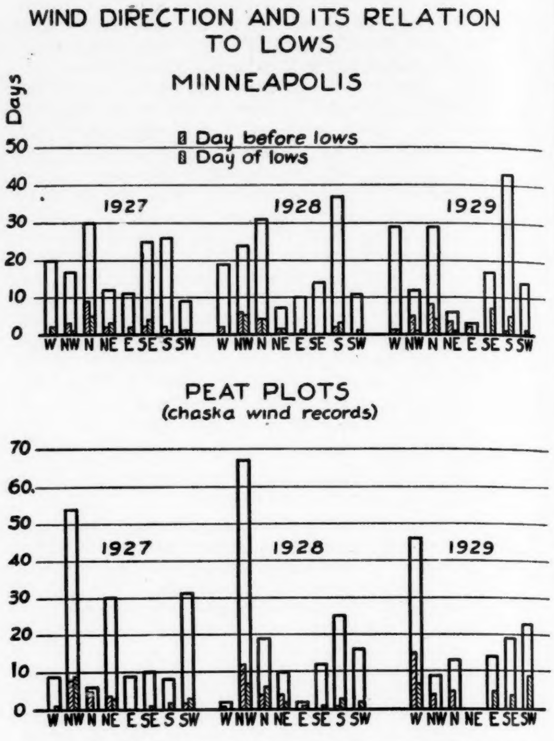

Fig. 9. Wind direction in relation to temperature lows

after a rain, the tendency being for them to be lower the second morning after the rain than they are the morning of the rain or the first or third morning after.

WIND DIRECTION TRENDS

The records of wind direction both at the Minneapolis station and at Chaska were considered. At each station one representative reading is given for each day, but there is little similarity between the two. The Minneapolis record for each day is based, however, on several observations made at various times throughout the day.

The summary for the wind directions for each season, expressed as percentages of the total number of days in the observation season for each year, appears in Table XVI.

The different years show little similarity. Apparently there is no cyclic tendency in the wind directions during the observation period. Neither does there seem to be any regular order of occurrence of the winds from the various directions. At no times of the season does there seem to be more winds from any given direction than are to be found at other periods of the season.

WIND IN RELATION TO TEMPERATURE

Wind seems to have quite an effect on temperatures. A prolonged period of southerly winds generally raises the temperature levels. A north or northwest wind, even for only a day or two, usually tends to lower both maximum and minimum temperatures at the peat plots. The

TABLE XV
AVERAGE MINIMUM TEMPERATURE FOR THE DAYS OF AND FIRST AND SECOND DAYS AFTER A RAIN

Time	1927	1928	1929	Ave. 3 Seasons
Day of rain	48.2	47.6	52.8	49.0
First day after rain	41.1	43.0	41.6	42.0
Second day after rain	39.3	35.5	40.1	37.9
Third day after rain	38.1	35.5	49.8	46.4

TABLE XVI
SUMMARY OF WIND DIRECTIONS
(Per cent of Total Time)

Wind Direction	1927 Chaska	1927 Mpls	1928 Chaska	1928 Mpls	1929 Chaska	1929 Mpls
Northwest	36.8	11.3	43.8	15.7	37.1	7.8
North	4.1	20.0	12.4	20.2	7.3	18.9
Northeast	13.6	8.0	6.5	4.6	10.5	3.9
East	6.1	7.3	1.3	6.5	0.0	2.0
Southeast	6.8	16.7	7.8	9.2	11.3	11.1
South	5.5	17.3	16.4	24.2	15.3	28.2
Southwest	21.0	6.0	10.5	7.2	18.5	9.2
West	6.1	13.3	1.3	12.4	0.0	18.9
Totals	100.0	100.0	100.0	100.0	100.0	100.0

TABLE XVII
PERCENTAGES OF WINDS FROM GIVEN DIRECTIONS WHICH OCCURRED ON DAYS BEFORE AND DAYS OF LOW TEMPERATURES

General Wind Direction	Minneapolis 1927	Minneapolis 1928	Minneapolis 1929	Peat Plots 1927	Peat Plots 1928	Peat Plots 1929
Days before low temperatures						
Northerly	23.7	17.7	34.0	18.9	20.8	35.3
Southerly	8.3	3.2	1.4	4.1	1.9	1.8
Days of low temperatures						
Northerly	15.3	16.1	12.8	15.0	15.6	10.3
Southerly	10.0	6.5	17.6	12.2	14.0	32.1

total number of days during each season for which the wind was in the given directions, and also the total number of days for which the wind was in each of the given directions the days before and days of the cold mornings is shown in Fig. 9. Table XVII shows both the percentage of days with the listed wind direction, which were followed by cold mornings, and also those which had cold mornings. That is, the 23.7 per cent for northerly winds under the heading of "Day before Low Temperatures" in 1927 means that 23.7 per cent of the days with northerly winds were followed by cold mornings. East and west winds seemed to fall between the classifications given and so were used as the dividing directions.

When the wind is in a northerly direction, there is a much greater chance that the following morning will be cold than there is when the wind is in a southerly direction. On the average, if the wind is northerly at Chaska on a given day, there is one chance in four that the following morning will be cold at the peat plots. If the wind is southerly, there is one chance in thirty-eight that the following morning will be cold. This general tendency is strongly supported by the general summary and Table XXIII. On the days of the temperature lows, however, the difference between the wind directions seems to have largely vanished. The percentage of southerly winds on the day of a low minimum temperature was peculiarly high in 1929. Although in 1929 the wind was almost always in a northerly direction the day before a cold morning, it was generally in a southerly direction the day of the low minimum. The relation of wind shifts to low minimum temperatures is further brought out for 1929 by Table XVIII, which concerns itself with those mornings on which the minimum temperatures at the peat plots fell 9 degrees or more below those at Minneapolis. For all three seasons the records of minimum temperatures are those from Station 3 on the one-foot control (Fig. 2). Under each of the three southerly wind directions listed are given the percentages of the time for which a shift of wind from the east, northeast, north, northwest, or west to the listed direction gave a minimum temperature 9 degrees or more lower at the experimental tract than at Minneapolis, the difference in minimum temperatures being taken the morning of the day when the wind was in the southerly listed direction. That is, a south wind following a south wind would not be considered, but a north wind followed by a south wind would be investigated on the morning when the wind changed to the south to determine the difference between the minimum temperature at Minneapolis and at the peat plots. In the first column of the table the percentage of the total number of mornings, that is, the number of mornings on which the minimum temperature was 9 degrees or more lower at the peat plots than at Minneapolis, is given for each season. The other columns give the percentages that the number of such shifts to the particular direction appearing at the head of the column at times when the 9 degrees or greater variation occurred, is of the total number of times when the wind shifted from some direction other than one of the three listed.

TABLE XVIII
DEVIATIONS OF MINIMUM TEMPERATURES AT PEAT PLOTS FROM THOSE AT MINNEAPOLIS AND THEIR RELATION TO WIND SHIFTS

Year	Minneapolis Record: % of 9° or Greater Deviations In Season	Minneapolis Record: Corresponding % Total Wind Shifts to SW.	S.	SE.	Chaska Record: % of 9° or Greater Deviations In Season	Chaska Record: Corresponding % Total Wind Shifts to SW.	S.	SE.
1927	46	67	64	77	44	69	100	42
1928	39	75	60	56	39	86	50	40
1929	33	67	56	50	36	81	86	75
Ave. 3 Seasons	39	70	60	61	40	79	79	52

While these percentages are based on so few instances that many variations are found, yet the fact remains that a shift of wind from some direction other than southerly to a southerly direction is often associated with a lower minimum temperature at the peat plots than at Minneapolis. In this table it is again seen that the deviations correlate especially closely with Chaska wind shifts in 1929. No adequate explanation of this tendency has been found unless it be because of location in the same valley with more nearly comparable topographic and soil conditions.

RELATIONS AMONG OTHER CLIMATOLOGICAL FACTORS

As far as can be determined there is no relation between cloudiness and wind direction. Examination of the data reveals no apparent relation between cloudiness and barometric pressure. However, averages for each season show the barometric pressure in general runs somewhat lower on cloudy days than it does for the season. This appears to be due to the fact that cloudiness attends the storm periods when the barometer is low, for cloudiness

TABLE XIX
BAROMETRIC PRESSURE IN RELATION TO CLOUDINESS
(6:47 p.m. Barometer Readings at Minneapolis)

Period	1927	1928	1929
Ave. pressure for season	28.95	28.91	28.98
Ave. pressure for cloudy days of season	28.93	28.87	28.96

TABLE XX
CLOUDINESS IN RELATION TO HUMIDITY
(Minneapolis Records)

Period	1927	1928	1929
Ave. humidity for season	57.00	54.00	51.60
Ave. humidity for cloudy days of season	64.20	64.00	59.80

TABLE XXI
PERCENTAGES OF WINDS FROM EACH DIRECTION OCCURRING UNDER RISING, CONSTANT, AND FALLING BAROMETER

Barometer	Percentages and Wind Directions NW.	N.	NE.	E.	SE.	S.	SW.	W.
			1927					
Rising	65	76	67	33	37	16	38	24
Constant	12	7	8	25	0	4	0	14
Falling	23	17	25	42	63	80	62	62
			1923					
Rising	42	45	66	50	36	22	44	63
Constant	21	13	17	0	28	8	0	5
Falling	37	42	17	50	36	70	56	32
			1929					
Rising	58	72	83	67	29	12	29	38
Constant	8	7	0	33	24	12	7	17
Falling	34	21	17	0	47	76	64	45

TABLE XXII
PERCENTAGES OF WINDS FROM THE VARIOUS DIRECTIONS OCCURRING DURING THE SEASON ON THE DAYS BEFORE, AND ON THE DAYS OF RAINS

Classification	NW.	N.	NE.	E.	SE.	S.	SW.	W.
			1927					
Season	11	20	8	7	17	17	6	14
Day before rain	8	12	4	12	24	32	0	8
Day of rain	16	12	4	4	20	16	12	16
			1928					
Season	16	20	5	7	9	24	7	12
Day before rain	12	4	4	12	16	24	12	16
Day of rain	24	32	0	4	16	16	0	8
			1929					
Season	8	19	4	2	11	28	9	19
Day before rain	8	13	0	0	13	37	8	21
Day of rain	4	25	0	0	17	25	12	17

at other than storm periods is not accompanied by a low barometer. The average barometric pressure for each season and for the cloudy days of each season, given in Table XIX, for the three years considered, seems to confirm this latter conclusion.

Humidity and cloudiness are as one would suspect, closely related. High humidity and cloudy weather usually go together. There are some partial exceptions to this tendency, but it seems fairly certain that the really high humidities occur generally under cloudy conditions. Table XX shows the average relationship. The difference between the average humidity for the season and for the cloudy days varies from 7.3 per cent in 1927 to 10.0 per cent in 1928.

Cloudiness and precipitation are closely related. Not only does precipitation occur when it is cloudy, but cloudy spells of two or three days often surround a rain.

Table XXI indicates some of the relations between barometric pressure and wind directions. The barometric pressure at 6:47 p.m. the day on which the wind occurred is compared with that at 6:47 p.m. the preceding day.

The percentages for constant barometer are quite variable and do not seem to lend themselves to any definite conclusions. The east and west winds occur in varying percentages under the different barometric pressure conditions. The northerly winds occur largely under the influence of a rising barometer and the southerly ones under that of a falling barometer. The table seems to indicate that the northeast and the south winds show the strongest tendency to follow the barometric changes.

The relation between barometric pressure and storms has been so thoroughly covered by the U. S. Weather Bureau, that nothing could be added by a discussion of it here.

How much relationship is there between rains and wind direction?

The wind direction the days before and the days of rain of 0.10 inch or more for the three years was studied. The Minneapolis wind records and the precipitation records taken at the peat plots are used for this study, the results being shown in Table XXII.

There are a few tendencies apparent in the table. The percentage of southeast winds that occur both the day before and the day of a rain is greater than the percentage of southeast winds for the season. The percentage of northeast winds is lower than the seasonal average both for the days before and for the days of rains. North and northwest winds are below the seasonal average for the days before rain. South winds occur more frequently the days before rains, and less frequently the days of rains than they normally occur throughout the season.

GENERAL SUMMARY OF CLIMATOLOGICAL PHENOMENA OCCURRING ON THE DAY BEFORE AND THE DAY OF A FREEZING TEMPERATURE

In connection with this discussion refer to Table XXIII. The usual weather conditions occurring on a day before a freezing temperature are rising or constant barometric pressure, low humidity (below normal, 57 per cent), a clear sky, and a north wind. All four of these conditions occur ten out of eighteen times. Three of the four conditions prevail for the other eight times.

The barometric pressure is rising or constant in every case on the day before a freezing temperature, while on the day of, it is just as apt to be falling as rising. The relative humidity shows a general tendency to be low on the day before a freezing temperature, although it is above normal as much as one-third of the time. The humidity is almost invariably low on the day of a freeze. Four of the five times that it is reported cloudy the day before, it is clear the day of the freeze, indicating that it cleared the evening or night before. There is only one time when there is a south wind the day before a freezing temperature occurs. On the day of this freeze, the wind was in the north, indicating that it had changed the night before. On the day of a freeze, the wind is in the south 60 per cent of the time.

Although the temperature shows a tendency to drop

TABLE XXIII
COMBINATIONS OF CLIMATOLOGICAL PHENOMENA OCCURRING ON THE DAY BEFORE AND THE DAY OF A FREEZING TEMPERATURE

Combinations of Climatological Phenomena	Number Times Combinations Occurred on Day before	Day of	Combinations of Climatological Phenomena	Number Times Combinations Occurred on Day before	Day of
Rising or constant barometer low humidity* clear sky† north wind	10	11	Rising barometer low humidity clear sky south wind	1	2
Rising or constant barometer high humidity cloudy sky north wind	5	1	Falling or constant barometer low humidity clear sky south wind	0	14
Rising barometer high humidity clear sky north wind	2	0	Miscellaneous weather combinations	0	1
			Totals	18	29

*Low humidity below normal (57).
High humidity above normal.
†Clear sky also includes partly cloudy.

during the two days following a rain, there is no general tendency toward freezing temperatures. There are only four times in the three seasons when a frost occurs two days after a rain.

This report is written in the early half of 1930. During the observation season of 1930 complete field data for the season are being secured, all at the experimental tract, with the aid of additional meteorological instruments so that for this year (1930) recourse need not be had to weather records taken at such a distance from the tract as was found necessary in preceding years. It is hoped later to give a complete report on the observations of the season of 1930 as a check upon the results and conclusions set forth in this paper.

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An Educational Program in Farm Machinery

TO SHOW the relationship between the different groups and organizations helping to solve the machinery problems of South Carolina farmers, J. T. McAlister, extension agricultural engineer of that state, has prepared a simple diagram with the above heading.

It shows a direct flow of information from the implement manufacturers, through their branch houses, to their local dealers and thence to the farmers, paralleled by a flow of information from the extension service of the U.S.D.A. division of agricultural engineering, through the Clemson Agricultural College division of agricultural engineering and extension service, to the county agents and from them to the farmers. The diagram also indicates cooperative relations and interchange of ideas between local dealers and county agents; between the branch houses and the college agricultural engineering extension service; between the implement manufacturers and the extension service of the U.S.D.A. division of agricultural engineering; between the National Association of Farm Equipment Manufacturers and both the implement manufacturers and their branch houses; and between the A.S.A.E. and the extension agricultural engineers of both the U. S. D. A. and Clemson College.

The diagram is used primarily in agricultural engineering schools for dealers, at which they are also given copy of the following general statement of the farmer's machinery problems:

"Analysis of production costs on farm products show that approximately 60 per cent of the total is made up of labor and power.

"Farmers need to make a special study of their methods of applying labor and power to the various operations performed in growing a crop in order to plan for the more efficient uses of these items through machinery.

"Under present conditions it is imperative that production costs be reduced. Demonstrations conducted by the extension service during the past two years show that with the efficient use of labor and power through machinery this fact can be realized."

Agricultural Engineering Digest

A review of current literature on agricultural engineering by R. W. Trullinger, specialist in agricultural engineering, Office of Experiment Stations, U. S. Department of Agriculture. Requests for copies of publications abstracted should be addressed direct to the publisher.

Nebraska Tractor Tests, 1920-1929 (Nebraska Station (Lincoln) Bulletin 242 (1930), pp. 27, pl. 1, fig. 1).—This bulletin summarizes the results of 61 tractor tests and includes data on all tractors reported by their manufacturers as on the market January 1, 1930.

Precooling of Fresh Fruits and Temperatures of Refrigerator Cars and Warehouse Rooms, E. L. Overholser and B. D. Moses (California Station (Berkeley) Bulletin 496 (1930), pp. 34, figs. 9).—This bulletin is a contribution from the station and the California Committee on the Relation of Electricity to Agriculture. Studies were made of air and fruit temperatures in commercial warehouse cold-storage rooms used for precooling, air and fruit temperatures at different positions within the refrigerator car as affected by car precooling, the rate of temperature drop in the fruit within the packages and in the air outside the packages, and the differences in rate of temperature fall as affected by the kind of fruit and type of package.

In the warehouse, when pears were surrounded by air currents having temperatures of 30 to 35 F, it required from 45 to 50 hours to cool the centers of the fruit packed in the centers of standard boxes, from 60 to 75 F down to 33 to 35 F. Extraction of the heat from wrapped packed pears is primarily by conduction. Packed boxes of grapes cooled somewhat more rapidly than did packed boxes of pears. With grapes the individual fruits were not so tightly packed together and were unwrapped. Grapes were cooled from 60 F down to 35 F in about 33 hours in a warehouse. The precooling of wrapped oranges packed in standard orange boxes required more time than did any of the other fruits studied. Oranges in the centers of each half of the divided orange box were cooled from 74 F down to 35 F after about 64 hours' storage in warehouse temperatures of 33 F. Warehouse precooling is adapted to concentrated fruit areas, shipping terminals, or commercial centers, while the portable type of cooler is adapted to those areas not having warehouse facilities, and to small shipping center or individual packers.

Loading of different styles of packages together in one end of the car obstructs air circulation and interferes with the effectiveness of car precoolers and the natural circulation of cold air from the ice bunkers. When the individual fruits of a package are wrapped and tightly placed together, the rate of cooling is retarded as contrasted with that of fruit which is unwrapped and loosely packed. The wrappers serve as insulators and also reduce the space for air movement, and heat is of necessity removed primarily by conduction. Open packages and loose packs permit convection currents, and thus facilitate the removal of heat. Small fruits cool somewhat more rapidly than large fruits. The small fruits have a larger surface per unit of volume, and this permits of more rapid reduction in temperature. Packed wrapped pears in the centers of standard boxes were cooled from 69.5 to 59.7 F with 6 hours of operation of a car precooler when the car was loaded only with pears. In a mixed load containing plums, grapes, and pears, the temperature of the pears in the center of the boxes was lowered from 67.5 to 63.5 F with 6 hours' operation of the car precooler. Grapes in Los Angeles lugs were cooled from 60.8 to 52.3 F within 3 hours.

Wrapped packed peaches with ice only dropped 3.4 F in 2 hours after loading. When a car precooler was operated during the same interval of time, the temperature of the peaches in another similar car dropped 8.2 F. The fruit in the car with the precooler continued to cool through the afternoon while that in the plain iced car warmed up, until after 7 hours of operation the drops were 1.8 and 15.4 F, respectively.

The importance of the initial fruit temperature as influenced by the time of day the fruit is harvested and packed is emphasized in view of the comparative difficulty in removing the heat after the fruit is packed.

It costs in addition to transportation charges about $105 for the delivery of a pre-iced car with average re-icing en route to Chicago. The delivery of a dry car costs $21. To manufacture and put ice in a dry car costs about $4.50 a ton. The icing with 15,000 lbs, would cost about $34, and this plus the initial cost of the dry car would effect a saving of about $50 when the car was not re-iced en route.

Combine Harvester Threshers in Michigan, E. C. Sauve (Michigan Station (East Lansing) Special Bulletin 198 (1930), pp. 19, figs. 8).—The results of field tests and observations of combine operations are reported. These were supplemented by a questionnaire.

At the completion of the 1929 grain harvest, 54 combines were known to have been used in Michigan. In 1928 there were 33, while in 1927, the first year of combine use, there were 7 combines in the state. The total average acreage harvested during the 1929 harvest by the 10-foot combines was 156 acres, 18 per cent of this being custom work. The average capacity of the 10-foot combine was approximately 2 acres per hour.

Shattering of the grain, particularly wheat, due to leaving it stand for the combine, was small. The time allowed after the binder harvest date before combining was 1 to 2 weeks. Heavy winds, hail and rain are hazards the combine user must face. The development and more general use of the windrower seems to be a solution to this problem. During the 3 years of combine use, the 1928 harvest was the most unsatisfactory because of excessive green material in the grain. Some grain harvested with the combine was not accepted by the elevators as marketable. Unevenness of ripening has not seriously reduced market quality. During the 1929 harvest, 9 of 28 owners who reported conserved a part of the straw by using a hay loader or buckrake, hauling to the barn, or baling in the field.

Under favorable weather conditions the combine, when properly equipped with a regular bean cylinder and concaves with proper speed reductions and sieves, will do a satisfactory job of harvesting and threshing navy beans, either as a stationary outfit in the field or in motion by using a windrow pick-up. The presence of stones is a hindrance to successful operation.

The estimated cost on an acre basis for harvesting grain with a 10-foot combine with separate motor and 2 men is $2.82 per acre. This cost is based on an average yearly acreage combined of 156. Where a windrower and windrow pick-up are used, the additional operation of windrowing will cost about $1 an acre, the cost being based on the average acreage now harvested by combines in Michigan.

Electric Brooders, F. E. Price, A. G. Lunn, and F. E. Fox (Oregon Station (Corvallis) Bulletin 262 (1930), pp. 24, figs. 16).—This bulletin, prepared in cooperation with the Oregon Committee on Electricity in Agriculture, presents the results of experimental work with electric brooders to determine power requirement, rate of growth, quality of the chick, mortality, and convenience and dependability in the operation of various types of electric brooders.

The cost of heat for brooding chicks was found to be approximately the same when using electric brooders of good construction at the rate of 3 cents per kilowatt-hour as when using a coal stove with briquets at $17 per ton. The labor required in operating electric brooders is much less than for coal-stove brooders.

Well-constructed electric brooders automatically maintain a very uniform brooding temperature. Electric brooders should have sufficient heating capacity to maintain a temperature of 100 F with no chicks under the hover during the coldest brooding weather. They may be equipped with full automatic heat control or may have only part of the heating elements equipped with automatic control and the remainder with a hand snap switch control. Full automatic heat control is decidedly superior. They do not require supplemental room heat when the outside temperature is only slightly below freezing. Chicks were brooded successfully with electric brooders without supplemental room heat with an outside temperature as low as 4 F.

A roosting platform of 0.5-inch mesh hardware cloth supported by a frame of 1 by 3-inch lumber on edge is recommended to provide a sanitary roosting place. Electric brooders should provide under the hover 7 square inches per chick and 12 square inches per poult.

Electric brooders eliminate a fire hazard that exists when using fuel-burning brooders. Power interruptions of one to two hours will not injure the chicks if proper management is followed. There is a large variation in different types and makes of electric brooders, and some are more satisfactory than others.

The Combined Harvester-Thresher in Montana, A. E. Starch and R. M. Merrill (Montana Station (Bozeman) Bulletin 230 (1930), pp. 59, figs. 42).—The results of a survey of the combine situation in Montana, conducted cooperatively by the station and the U.S.D.A. Bureaus of Agricultural Economics, Public Roads and Plant Industry, are reported. Many of the tables are based on the records taken in the Judith Basin, Mont., during the harvest season of 1926. The results of additional experiments on the adaptation of the combine harvesting method to Montana conditions, the use of such equipment as the supplemental header, and methods of saving straw, as carried out in 1927 and 1928, are also included.

The acreage cut annually ranges from 337, which was the average for 8-foot machines, to 1,060, the average for the 20-foot machines. A fair rule for determining the acre capacity of a machine is to figure 0.25 acre per hour for each foot of width. The cost of operation was 13.7 cents a bushel. The fuel consumption of gasoline was about 1.2 gallons an acre. As the fixed expense is high due to the first cost of the machine, it is imperative that the machine be fully utilized.

The losses in the field and in threshing are comparatively low. The field losses averaged 2.6 per cent for the combine, 3.8 per cent for headers, and 6.1 per cent for binders. The threshing losses for the combines averaged 1.9 per cent and for stationary threshers 1.1 per cent.

The supplemental header was found to enable the operator to cut costs when yields are low. The windrow pick-up and the shock pick-up enable the operator to harvest a larger acreage because the harvest season can be lengthened by cutting with a windrow or a binder until the crop is fit for combining and then coming back to windrows or shocks at the close of the season. Uneven ripening and weedy grain may also be handled by these methods.

It was found that combining should not be undertaken before the moisture content of the grain is reduced to 14 per cent.

The Combine Harvester in Missouri, M. M. Jones (Missouri Station (Columbia) Bulletin 286 (1930), pp. 39, figs. 8).—The material presented in this bulletin is the result of studies of harvesting methods conducted during the harvest seasons of 1928 and 1929. The main object of these studies was to determine if the combine method of harvesting is practical and economical under Missouri conditions.

About 15 combines were used in Missouri in 1927, about 65 in 1928, and about 115 in 1929. Combines have been successfully used for harvesting wheat, oats, rye, barley, timothy and soybeans, and also sweet, red and alsike clover when windrowed. The 10-foot size of combine seems to be the most popular and practical in Missouri. Twenty to 25 acres per working day during harvest season is a good average day's work. Combines of the 10-foot size are most commonly pulled with tractors of 10 to 15 drawbar horsepower. Combine owners estimate that their machines will last about 10 years.

Badly lodged grain can be picked up with a combine with less loss than with a binder. Combines generally have to travel slower in lodged grain than in grain that stands well. The difference in the grain lost by the combine method and the binder-thresher method is small. Green weeds growing up in the ripened grain were the most serious handicap to combine operations in 1928 and 1929. The windrow system of harvesting has been successfully used by some Missouri farmers in combating the trouble from green weeds, and it appears that it could be used to advantage by many others. Combined grain compares favorably in quality with grain threshed from the shock. It appears that the combine method of harvesting in Missouri is limited more by the type of farming and the acreage of small grain and seed crops grown than by weather conditions. In the opinion of the most of the combine owners, a farmer should have about 100 acres of small grain to justify owning a 10-foot combine. The maximum acreage of wheat that a machine of this size should be depended on to harvest, in their opinions, is about 300.

One man on the combine and one on the tractor is the average operating crew. If the grain is sacked an additional man is required. Experience to date indicates that a crop can be harvested and threshed with a combine with no more labor than would be required to shock the grain if cut with a binder. Custom work has been found satisfactory for a number of combine owners, and also for those whose grain was so harvested. A charge of $2 per acre plus 10 cents per bushel for combining wheat is generally considered to be fair to both parties. Average harvesting costs on acreages above 75 or 80 are lower with a combine than with the binder-thresher method. For acreages below this the binder-thresher method is usually cheaper. The average cost of harvesting with the combine method on 28 Missouri farms in 1929 was $2.02 per acre, or 21.7 cents per bushel. The average cost of harvesting and threshing with the binder-thresher method on 93 farms in 1929 was $3.85 per acre, or 37.5 cents per bushel.

Effect of Variations in Temperature on the Operation of the Instantaneous Reading Atmometer, J. E. Christiansen, F. J. Veihmeyer, and C. V. Givan (Ecology (Brooklyn, N. Y.), 11 (1930), No. 1, pp. 161-169, figs. 4).—Experiments conducted at the California Experiment Station are reported. These showed that rates of evaporation can not be read accurately from the instantaneous reading atmometer unless the temperature of the water in the reservoir is nearly constant, or unless a correction is introduced to care for changes in rates caused by temperature and consequent viscosity variations in the water surrounding the resistance member. The rate of evaporation is directly proportional to the head only for a constant temperature. Flow through the resistance member is directly proportional to the head and inversely proportional to the coefficient of viscosity of the water ,and may be expressed by the relation $\mathbf{R} = \mathbf{KH}/u$, in which **R** is the rate of evaporation in cubic centimers per hour from the atmometer, **H** is the head in centimeters, **K** is a constant for a particular resistance member, and u is the coefficient of viscosity of the water in centipoises. The constant **K** must be determined for each resistance member by special tests. A bibliography is included.

Book Reviews

"Agricultural Machinery," by J. Brownlee Davidson, professor of agricultural engineering, Iowa State College, is a new addition to the Wiley agricultural engineering series of which Mr. Davidson is editor. It is published as a text and reference for users and managers of agricultural machinery; for agricultural engineering students; for designers and manufacturers of agricultural machines. It includes, for the benefit of those who have not had extensive instruction in these subjects, certain phases of mechanics, mechanics of materials, materials used in machine construction, and the elements of machine design. Instruction on the repair of farm machines is not included as the author indicates a belief that this is subject matter which can better be handled in practical farm mechanics and shops courses. No attempt is made to cover all farm machines but information is given on a well-rounded selection of the more important kinds and types. This book is something more than a compendium of mechanical information as the introductory chapter takes up "The Relation of Agricultural Machinery to Agricultural Progress" and there are other chapters on the "Life, Use and Cost of Agricultural Machines," "Selection and Management of Agricultural Machines," and "The Manufacture of Agricultural Machinery in the United States." 396 pages, 6x9 inches, 600 figures, subject matter index, cloth bound. John Wiley and Sons, Inc., New York. $3.00.

Corrections

IN THE article "The Combination Cushion Spring and Clutch Release Hitch," by E. G. McKibben, appearing on page 87 of AGRICULTURAL ENGINEERING for March, equation 5 was not correct as printed. It should read

$$\frac{Fd^2}{2} - \frac{T^2}{2F} - T\left[d - \frac{T}{F}\right] \qquad [5]$$

Insertion of this correction makes logical the derivation of equation 6, which is correct as printed.

ATTENTION has been called by G. D. Jones to the fact that in his article entitled "General-Purpose Tractor Design," published in the March issue, the third from the last paragraph as edited and printed does not convey the intended meaning. The following publication is therefore given to that paragraph, copied verbatim from the manuscript:

> Time permits only a very brief description of my idea of the future general-purpose tractor and we can boil down the requirements about as follows—a completely balanced tractor, wherein as much of the weight during the pulling operation is carried directly over the drive wheels and more or less evenly distributed over the entire tractor when operating without load; means for widening and narrowing, raising and lowering; complete visibility with perhaps two seats and simple easily operated steering means. This would lead us to a design about as follows; —the two driving wheels, adjustable for width and height; the driving mechanism being located in this as in the conventional tractor; directly between the driving wheels is located a seat with control members, for steering, clutching and changing speed; then the motor and radiator; at the rear of the radiator allowing sufficient room for another seat and control members; and below a castor wheel, which is also adjustable both for height and lateral adjustment. A dual control, fore and aft, and if necessary, use only one seat which could be taken out easily and moved from front to rear or vice versa. This unit would have the implements for cultivating and like work pushed ahead and those implements, such as plows and harrows, pulled from the rear. With this design, as the load increased, the torque load would be carried on a rolling member instead of exerting an enormous effort in attempting to lift the front of the tractor as it does when the driving wheels are located at the rear, and the weight of the engine, radiator and front wheels must be relied upon to hold the front end in contact with the soil. This tractor would resemble a three-wheel tractor running backwards. This is not a difficult problem if we forget the conventional tractor design and really build a general-purpose tractor to meet the general farming needs.

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Contributions of interest and value, especially on new developments in the field of agricultural engineering, are invited for publication in this journal. Its columns are open for discussions on all phases of agricultural engineering. Communications on subjects of timely interest to agricultural engineers, or comments on the contents of this journal or the activities of the Society, are also welcome.

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RAYMOND OLNEY, Editor

R. A. Palmer, Associate Editor

Agricultural Engineering on Boulder Canyon Project

THE Boulder Canyon project is a work calculated to greatly stimulate both the industrial and the agricultural development of the Southwest.

The public land to be reclaimed for agricultural purposes has been withdrawn from settlement pending completion of Hoover Dam and its accessory works some seven or eight years hence. When irrigated this land may be used to grow a wide variety of the crops common to temperate and subtropical climates, such as alfalfa, cotton, winter vegetables, cantaloupes, lettuce, pecans, citrus fruits, figs and dates.

Present plans of the U. S. Bureau of Reclamation are to successively open for settlement units of the land of several thousand acres each, developing additional units as warranted by the full settlement of the developed units. Furthermore, the Bureau plans to so supervise settlement as to reasonably assure that the farmers will be able to earn a living and pay all government charges upon their land. Before permitting any man to settle it will determine that he has the capital and farm experience necessary to succeed.

But success is measured by uncertain and changing standards. During the next seven or eight years there will probably be a continued rise in farm standards of living; in acreage per farm; in the capital and knowledge requirements for success in agriculture. By that time the trend of progress in agriculture under the influence of constantly improving equipment and scientific knowledge should be well defined.

The Bureau will have an opportunity to set up communities in accordance with its ideas as to what constitutes success in agriculture; as to what agricultural methods, productivity and standards of living should be.

It might establish rigid requirements and develop whole communities that would be ten or twenty years ahead of the general run of farmers. It might be extremely conservative, admitting the typical, old-fashioned, 16-hour day, "dirt farmer" or small farmer, and discouraging the modern large-scale family farm. It might adopt a fairly open policy which would place farmers with widely varying capital and abilities in competition side by side, as in areas settled with little or no supervision. Or it might vary its requirements in different sections of the reclaimed area, creating comparable case studies of different policies in farm community development.

Many authorities on the subject say that agriculture needs to be reorganized to meet present conditions. Here the Bureau will have a chance to start clean, with new materials and with no old habits, local customs, traditions or bad economic situations to overcome, to so plan whole agricultural communities that they may compete on an even basis in the commerce of the day and adapt themselves to its continual changes.

Whatever standard of productivity and living the Bureau actually fosters on this project when the time comes, its supervision will give this standard and the means of achieving it a fair trial on a community basis. To the extent that it involves the application of engineering knowledge, materials and equipment on the individual farms, it will demonstrate the benefits of agricultural engineering as they have never yet been demonstrated. That angle of the project will be of particular interest to agricultural engineers.

Food for Thought at Joint Meeting on Land Reclamation

CONSIDERABLE food for serious and constructive thought was contained in the short address by Miss Mae A. Schnurr before the recent joint meeting of the Land Reclamation Division and Pacific Coast Section of the American Society of Agricultural Engineers at San Francisco.

Miss Schnurr, who is assistant to the commissioner of the U. S. Bureau of Reclamation, briefly described the purpose of the Boulder Canyon Project, and touched on some of the effects of this project on future agricultural and other industrial development in the Southwest.

The greatest significance of this project was pointed out to lie in the social and economic changes which the building of a single structure is destined to bring about. Already it has wrought a significant change in our water laws. It provides for the removal of the flood menace from the once desert and now fertile and fruitful Imperial Valley. It also will provide remarkable scenic attractions for tourists. The entire project is designed to increase the wealth and improve the living conditions over a wide area of the Southwest.

However, there would appear to be something especially significant to agricultural engineers in the fact that Miss Schnurr was sent across the United States to carry this brief and apparently very general and superficial message to the land reclamation group of our Society. No small part of this significance seems embodied in the statement made by Miss Schnurr that "public opinion would never have sanctioned approval of the Boulder Canyon Project Act if it could not be shown that the project would pay for itself." The further statement in this connection that "the development of hydroelectric power . . . . was finally accepted as the instrument to finance this project" is equally significant.

Sympathetic interest and confidence in agricultural engineering on the part of the U.S.D.A. Bureau of Reclamation undoubtedly was expressed by the presence of Miss Schnurr at one of our primary divisional meetings. However, these statements which she was authorized to make would indicate also that much is expected of agricultural engineers in helping to make this great undertaking an ultimate success. In fact, Miss Schnurr's statements would appear as a challenge to the ingenuity and industry of agricultural engineers interested in land reclamation and rural electrification. Thus another great opportunity is offered us to prove our worth, and again we will not be found wanting.

R. W. TRULLINGER.

A.S.A.E. and Related Activities

TENTATIVE PROGRAM

TWENTY-FIFTH ANNUAL MEETING of the AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Iowa State College, Ames, Iowa—June 22-25, 1931

First Day—Monday, June 22

Forenoon—9 to 12

College Division Session

S. P. Lyle, chairman, presiding

1. Business session; committee reports and general business
2. Engineering Educational Standards — L. W. Wallace, executive secretary, American Engineering Council
3. Agricultural Engineering Educational Standards — C. E. Seitz, head, department of agricultural engineering, Virginia Polytechnic Institute

Afternoon—2 to 4

Simultaneous Technical Division Sessions

Power and Machinery Division

O. B. Zimmerman, chairman, presiding

(Program not yet reported to the committee)

Land Reclamation Division

L. F. Livingston, chairman, presiding

(Program not yet reported to the committee)

Rural Electric Division

E. C. Easter, chairman, presiding

1. Distribution of Electric Service on the Farmstead—Roy Hayman, in charge of rural electrification, Oklahoma Gas and Electric Company
2. Characteristics of Rural Electric Distribution Lines—C. P. Wagner, manager, rural service department, Northern States Power Company
3. Threshing Machine Operations—T. E. Hienton, department of agricultural engineering, Purdue University
4. Systems of Electric Water Heating—Norman T. Wilcox, Stone and Webster, Inc.

   Discussion by A. V. Krewatch, electrical engineer, National Rural Electric Project

Visiting Hour

Those who wish to visit the agricultural engineering department farm at this time may do so by arrangement with E. V. Collins, agricultural engineer in charge

Evening—7:30 to 9:30

Group Conferences, Committees, Etc.

1. Council Meeting
2. Student Members' Meeting
3. General Committee Meetings

Second Day—Tuesday, June 23

Forenoon—9 to 11:30

Simultaneous Technical Division Sessions

Power and Machinery Division

O. B. Zimmerman, chairman, presiding

(Program not yet reported to the committee)

Structures Division

F. C. Fenton, chairman, presiding

(Program not yet reported to the committee)

Rural Electric Division

E. C. Easter, chairman, presiding

1. Irrigation East of the Rocky Mountains—Dr. F. E. Staebner, agricultural engineer, Bureau of Public Roads, U.S.D.A.
2. Orchard Irrigation—C. E. Seitz, head, department of agricultural engineering, Virginia Polytechnic Institute
3. Pasture Irrigation—F. E. Price, agricultural engineer, Oregon Agricultural College
4. Hay Curing by Artificial Methods — F. W. Duffee, agricultural engineer, University of Wisconsin
5. Grain and Forage Grinding — F. R. Jones, agricultural engineer, Texas A. & M. College

Afternoon—1:30 to 3:30

Simultaneous Technical Division Sessions

Land Reclamation Division

L. F. Livingston, chairman, presiding

(Program not yet reported to the committee)

Structures Division

F. C. Fenton, chairman, presiding

(Program not yet reported to the committee)

Rural Electric Division

E. C. Easter, chairman, presiding

1. Extension Work in Rural Electrification—S. P. Lyle, agricultural engineer, Bureau of Public Roads, U.S.D.A.
2. Rural Electrification Extension Work Promoted by Commercial Organizations—Douglas Dow, Detroit Edison Company
3. Refrigeration of Eggs on the Farm — P. T. Montfort, research agricultural engineer, Texas A. & M. College
4. Results of Survey of Research Work in Rural Electrification — Geo. W. Kable, director, National Rural Electric Project

Inspection—4 to 5:30

Exhibits in agricultural engineering laboratories

Historical machines in armory

In charge of Henry Giese

Evening—7:30

Annual Business Meeting of the Society

Third Day—Wednesday, June 24

Forenoon—9 to 11—General Session

R. W. Trullinger, president, presiding

1. Meeting called to order by H. B. Roe, chairman, Meetings Committee
2. Address of Welcome—R. M. Hughes, president, Iowa State College
3. Announcements—J. B. Davidson, chairman, Committee on Arrangements
4. The President's Annual Address — R. W. Trullinger, senior agricultural engineer, Office of Experiment Stations, U.S.D.A.
5. The Philosophy of Agricultural Engineering—J. B. Davidson, head, department of agricultural engineering, Iowa State College
6. Fitting Engineering into the Agricultural Picture—Hon. L. J. Dickinson, United States Senator from Iowa

Afternoon—1:30 to 3:30—General Session

R. W. Trullinger, president, presiding

1. The Contribution of Land Reclamation to Agricultural Engineering Development—James A. King, advertising and publicity manager for the Mason City Brick and Tile Company
2. One Hundred Years of Development in Tillage and Harvesting Machinery—Cyrus McCormick, Jr., vice-president, International Harvester Company
3. Address by Anson Marston, dean of engineering, Iowa State College

Agricultural Engineering Pageant

4 to 5:30

In the field in rear of Agricultural Engineering Laboratory, in charge of E. G. McKibben

Evening—6:30—A.S.A.E. Annual Dinner

R. U. Blasingame, Toastmaster

Fourth Day—Thursday, June 25

Forenoon—9:00 to 11:30—General Session

R. W. Trullinger, president, presiding

1. The Function of the Extension Engineer in the Reorganization of American Agriculture—B. B. Robb, extension professor of agricultural engineering, Cornell University
2. The Future of Chemistry in Agriculture — Dr. O. R. Sweeney, head, chemical engineering department, Iowa State College
3. Training of Research Workers—J. T. Jardine, director, Oregon Agricultural Experiment Station

Afternoon to Evening

Trip to Des Moines as Guests of the Meredith Publications, including

1. Visit to Wood Brothers Thresher Works, just out of Des Moines
2. Visit to the plant of the Meredith Publishing Co., publishers of "Better Homes and Gardens" and "Successful Farming"
3. Visit to Meredith Farm
4. Supper served at the Meredith Farm. Return to Ames or proceed to homes direct from Des Moines in evening.

Conference of the College Division Advisory Committee

PRESENT at the annual meeting of the A.S.A.E. College Division advisory Committee, held at Washington, D. C., March 9 to 11, were all members of the Committee: Chairman, S. P. Lyle, U. S. Department of Agriculture; F. C. Fenton, Kansas State Agricultural College; C. E. Seitz, Virginia Polytechnic Institute; E. E. Brackett, University of Nebraska; D. G. Carter, University of Arkansas; and R. W. Trullinger, S. H. McCrory and others from the U. S. Department of Agriculture.

Progress in research was discussed by Mr. Trullinger, and research and extension objectives, of the Bureau of Agricultural Engineering, which will be organized in the Department of Agriculture, were presented by Mr. McCrory and Mr. Lyle, respectively. The principal topic of discussion, agricultural engineering curriculum standards, was presented by Profs. Seitz and Brackett. Recommendations on such standards were agreed upon, and L. W. Wallace, Executive Secretary of American Engineering Council, has accepted an invitation to address the College Division on this topic at its annual meeting in June, at Ames, Iowa.

A program for a conference on methods and teaching agricultural

engineering, to be held at Ames, Iowa, in June, immediately preceding the annual meeting of the A.S.A.E. was presented by Professor Carter and approved by the Committee. It will consist of eight half-day sessions, each to include a lecture or discussion on teaching methods, a class exercise, and discussions and criticisms of the lecture and exercise.

Means for stimulation of student enrollment, in both collegiate and graduate work, were also discussed. Professors Fenton and Seitz were directed by the Committee to revise copy for a booklet entitled "A Glance at Agricultural Engineering" to make it available for immediate publication. Other topics were provisions for industrial employment of graduates, a personnel file for agricultural engineers, new aids for high school farm mechanics classes, experimental studies in teaching agricultural engineering subjects, a study of the need for dairy engineering courses, collegiate standards for vocational farm mechanics courses, state experiment station responsibilities in reference to erosion control problems, and college men's contribution to professional literature. Three new objectives, referring to publication standards, graduate enrollment and extension work, were proposed to be added to those formerly set up, but not yet completed. The minutes of this meeting are now in preparation for mailing to the college departments of agricultural engineering.

Public Domain Committee Supports Reclamation Policy

IN ITS report to the President of the United States, recently made public, the Committee on the Conservation and Administration of the Public Domain recommended that the present federal reclamation policy be continued.

The Committee, numbering twenty members, including leading engineers, lawyers, federal officials, state officials, writers, industrial executives and others who have had close contact with the problem, studied the public lands problem from all angles for nearly a year before reporting. Its special recommendation number 12, having to do with reclamation, reads as follows:

> The present conservative policy of reclamation development should be continued. Under it, construction expenditures each year are restricted to the payments from settlers and the income from other sources provided for in the law. If payments are not made, works will not be built. This makes of reclamation a sound business policy and is a strong influence toward maintaining the integrity of the contracts.
>
> Where projects require a larger investment than can be met from the reclamation fund, they should be dealt with by Congress in special acts similar in character to the Boulder Canyon project act.
>
> We recommend that, in the undertaking of any project, there should be no interference with the laws of the state relating to the appropriation, control, or distribution of the water or with vested rights secured thereunder.
>
> Past experience, coupled with the urgent need of additional funds for accelerating and continuing construction work on irrigation projects, points conclusively to the desirability of adopting a definite policy relative to hydroelectric development, under which the power receipts should be used; first, to repay the cost of the power plant and appurtenant works; second, the cost of the reservoir and dam which regulates the delivery of water to the plant; and, after that, all net revenues should be credited to the reclamation revolving fund.
>
> The policy should be continued of having a central organization to design and build works, but to transfer these works to the control and management of the water users as soon as the projects are settled and developed.

ASAE Meetings

Pacific Coast Section, spring meeting, University of California, Berkeley, Friday, May 1. General subject—Large-Scale Farming.

Twenty-Fifth Anniversary Annual Meeting, Iowa State College, Ames, Monday, June 22 to Thursday, June 25.

Personals of ASAE Members

M. C. Betts, architect, U.S.D.A., was recently appointed by Secretary of Commerce Robert P. Lamont, chairman of the National Committee on Wood Utilization, to represent the ASAE on a subcommittee which will prepare a booklet on home insulation. The booklet will be prepared as a cooperative project between government and industry to inform the nontechnical consumer of the advantages and economies of house insulation.

Max E. Cook has been promoted from the position of farmstead engineer to that of secretary-manager of the California Redwood Association, 405 Montgomery Street, San Francisco, California. In addition to the duties of this new office, he will also serve as manager of the Redwood Farm Structures Bureau, a departmental activity of the Association.

A. H. Hoffman, research agricultural engineer, University of California, is author of California Agricultural Experiment Station Bulletin 499, entitled "Air Cleaners for Motor Vehicles."

S. H. McCrory, chief, division of agricultural engineering, Bureau of Public Roads, U. S. Department of Agriculture, is author of an article describing the work of that division in the March 1931 issue of "Civil Engineering."

J. E. Waggoner, formerly sales promotion manager of the Oliver Farm Equipment Company, has been appointed director of research of "Electricity on the Farm," rural electrification magazine of the Case-Shepperd-Mann Publishing Corp. He will make his headquarters in Chicago.

Applicants for Membership

The following is a list of applicants for membership in the American Society of Agricultural Engineers received since the publication of the March issue of AGRICULTURAL ENGINEERING. Members of the Society are urged to send information relative to applicants for consideration of the Council prior to election.

Walter G. Bruce, teacher, Killingly High School, Danielson, Conn.

George M. Clarke, Jr., adjunct professor, Georgia State College, Athens, Ga.

Joseph L. Green, draftsman and experimental engineer, John Deere Spreader Works, East Moline, Ill.

Lawrence W. Smith, consulting representative, Southern Cypress Manufacturers Association, Jacksonville, Fla.

Nordahl L. Wallem, research worker, Montana State College, Bozeman, Mont.

Transfer of Grade

Rhuel G. Harvey, rural service manager, The Syracuse Lighting Co., Syracuse, N. Y. (Affiliate to Associate Member).

Russell H. Reed, instructor in farm mechanics, University of Illinois, Urbana, Ill. (Junior to Associate Member.)

New ASAE Members

W. D. Collins, power farmer, Fullfords, Sussex, England.

R. G. Ferris, research engineer, Starline, Inc., Harvard, Ill.

H. O. Hill, junior civil engineer, U. S. Department of Agriculture, Tyler, Tex.

J. H. Hough, rural electrification engineer, Baton Rouge Electric Company, Baton Rouge, La.

Frank W. Hussey, junior partner, Chas. E. Hussey & Sons, Presque Isle, Me.

Adolphe LeBron, project engineer, United Fruit Company, Puerto, Castilla, Honduras, C. A.

G. A. Mitchell, agent, Bureau of Public Roads, Magnolia Road, Vineland, N. J.

O. W. Monson, assistant professor in agricultural engineering, Montana State College, Bozeman, Mont.

L. S. Wing, engineer, California Farm Bureau Federation, San Francisco, Calif.

Transfer of Grade

E. G. Johnson, extension agricultural engineer, University of Illinois, Urbana, Ill. (Junior to Associate Member.)

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